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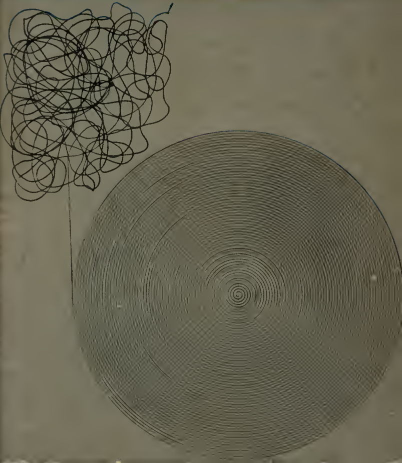
The Simplicity of Science

Stanley D. Beck



Dr Stanley D. Beck is a zoologist. He was brought up in the Cascade Mountains of Washington, and has been a scientist for as long as he can remember. As a child he had a woodshed laboratory where he read natural history books and built up a large collection of caterpillars and beetles. He worked his way through Washington State College as a laboratory technician in the Zoology Department, then, after war service in the Navy, gained his Ph.D. in zoology at the University of Wisconsin. He is now an associate professor there, specializing in the physiology of insects as they adapt themselves to various types of plants. He has written on this subject in the *Scientific American*.

Dr Beck's latent interest in the philosophy of science ripened after 1952, when a polio attack curtailed his zoological field work. He read avidly the works of Whitehead, Nagel, Russell, and many others, and also studied the Bible. Dr Beck is now an active Lutheran. He lives in Madison, Wisconsin, with his wife and four children.

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CONTENTS

I

IVORY TOWERS AND MARKET PLACES

EVERYWHERE on earth things change, for ours is a restless world. Tides rise and fall; days dawn and pass; season succeeds season, and years file away. Mountains push up, only to be worn down again. Giant glaciers slide southward to melt as the climate goes through its great cycle. Seeds sprout and grow into majestic trees, die, and return to the soil. Civilizations rise from the rubble of previous civilizations, to blossom, wither, and sink into oblivion. Plants, insects, men, and rocks go their appointed rounds and fade into the inscrutable past. This restlessness makes up the phenomena of our world, for a phenomenon is a change, an occurrence. A universe without change would be sterile and devoid of beauty and meaning.

The beauty and mystery of our world intrigues the mind of the curious, and presents a challenge to the adventurous, and the great adventure of today is to be found on the frontiers of science. An understanding of the phenomenal world may be sought only for the simple aesthetic value of knowing. Or it may be for the purpose of harnessing the forces of nature to make our lives more secure and comfortable; that we may pass on to our children a better way of life.

Exploring the intricacies of nature needs no justification beyond the mere fact that it is there, an ever-present challenge. An athlete will patiently train for months, and then – heart and lungs near bursting – he will strive to run a mile faster than any human before him. A small boy on a bicycle can go faster. The cinder track is oval; so that

when he has run the mile, he is back where he started. The only reason for trying to run a mile in record time is the challenge it presents. Many generations of men have tried to climb to the summit of Mount Everest. Scores failed, many of them leaving their broken bodies on the mountain. When the feat was finally accomplished, the men who did it were hailed as heroes. And yet when they reached the top, they were obliged to return to the base. Back from where they had started. The only real importance of their deed was that a great mountain had been conquered; a great challenge had been met.

The challenge justifies the effort. If the human mind were to become so sluggish that it was uninterested in the mysteries of nature, insensitive to the staggering challenge of the unknown, but involved only in a menial existence of food, drink, sleep, and reproduction, man would be distinguishable from the mamalian beasts only anatomically.

Through the ages that have spanned the time from primitive beginnings to modern complexity, man has made two demands of the world about him. First, he demands that the world shall provide a means of living in some degree of comfort and security. This is a biological requirement which is simple in essence and quite fundamental to the survival and perpetuation of the human race. But in addition to this biological need, man makes the intellectual demand that his world form a meaningful picture. However crude and provisional his knowledge may be, man must create answers to the questions he poses. If the mystery of life and universe is left unsolved, the world is chaotic and without meaning to him.

Contemplating the sun, the stars, his world, and himself, man has sent a yearning mind into the great unknown to seek a greater mind and the assurance of a

purpose, a reason, a value to his life. From deep within his being, he has felt the stirring of an unconquerable soul linking him with the eternal. Intuition, born perhaps of desire, assures him that he is not alone in the universe and that the essence of his life transcends any earthly grave.

The quest for comfort and security has resulted in knowledge of agriculture, engineering, communications, warfare, and medicine. These make up our technology – the ability to use the resources of the earth for our own purposes. This ever-expanding body of knowledge has been created, accumulated, and passed from one generation to the next as a means of satisfying our biological demands on nature. The intellectual demand for an understandable and meaningful world has resulted in the creation and perpetuation of bodies of knowledge differing from technology. These are religion, art, and science, and are ways of making sense out of a seemingly chaotic nature, ways of interpreting the world and our position in it. The biological and intellectual aspects of human existence are not independent of one another. From the intertwining of technology and ideology, the shape and destiny of a civilization is determined.

In respect to our own civilization, the twentieth century is the third century of the scientific age. From seeds of thought planted in ancient times, the scientific age germinated during the seventeenth century, to grow and bear fruit in the eighteenth, nineteenth, and twentieth centuries. The end of the age is not in sight. We are not at a crossroad; we are not in a crisis. We cannot now choose the direction of growth for our civilization. The choice has been made; all of Western civilization is committed to advancement through the application of scientific knowledge.

Our lives are touched daily by modern science. The way we think, how we spend leisure hours, the way we live, and even how long we live are all influenced by the scientific tradition of the century. Life expectancy figures grow higher each year, and a child born today in one of the industrialized countries is given a life expectancy twice as great as that enjoyed by his ancestors of two centuries ago. Many dread diseases, such as diphtheria, smallpox, and typhus, have been controlled almost to the vanishing point. Mortality during childbirth has been reduced to but a very small fraction of what it was but a few generations in the past. The list of advances in disease prevention and cure could be lengthened to truly impressive proportions, so avidly has the medical profession applied the results of scientific research. Compared to people from any other period of history, we not only live longer, healthier lives, but we also live more comfortably with greater material wealth. No one has ever before 'had it so good'.

Radio and television and radar and rockets and satellites have shrunk the earth, that men everywhere may be neighbours, and we are finding that it is not easy to be neighbourly. The admonition to 'Love thy neighbour' may yet become a rule for survival, rather than an easily disregarded platitude. Not only has the earth been reduced until the whole civilized world is but our back yard, but the adversities of the physical environment have been humbled. Radar penetrates the dark of night and knifes through the fog to guide ships and planes with safety and precision. Hurricanes and tornadoes are tracked that human activities in their paths may be modified to minimize storm damage. Within limits, rain can be made to fall where needed. With constantly more efficient destroyers of weeds and insect pests, ever larger quantities

of high quality produce come from the hybrid plants of the nation's farm lands.

By popular conception, science is synonymous with progress – progress in health, comfort, leisure, and material. It is also progress in speed – speed of travel, speed of communication, and speed of destruction of our enemies, be they man, plant, or animal. And it is progress in conquering the vicissitudes of earthly environment and, eventually, interplanetary space. In science the progress and destiny of the human race is supposed to lie. To be unscientific is thought to be unprogressive and irrational, if not downright psychotic.

With the great rise of science, there has come an effort on the part of all sorts of activities to be called scientific. This desire 'to get in the act' does not come from an understanding of science, but comes instead from a desire to be accepted. It is largely a matter of trading on the widespread belief that anything – beans, bombs, or beliefs – called scientific is better than anything not carrying that label. The faith we have in science comes from the tremendous technical success that can be traced to scientific endeavour, and we believe in success. Because of its success, we tend to expect science to solve all of our problems, physical or spiritual. And the sanction of science is sought or simulated as the guarantee of that success.

At the level of the nation, community, and individual, inroads have been made on privacy. Nation holds threat of nuclear warfare over nation. Public-opinion polls are conducted to tell us how we are going to vote even before elections are held. Statistically minded safety experts announce how many of us will kill ourselves in motor-cars over a holiday week-end, and even before the blood is cold on the concrete, we know that their prediction had a

ghastly accuracy. Television sets bring hosts of strangers into our living-rooms, there to gyrate with ghostly grace within the confines of their puddle of electronic blue and to sell us something. Brush your teeth with science's latest, and therefore best, toothpaste. Smoke scientifically superior cigarettes. Really live; live in a scientifically designed house. And so on *ad nauseam*.

If we are to live in an age of science, and indeed we must, it is very important that we understand the nature of science itself. If science were no more than antibiotics, plastics, insecticides, H-bombs, and all the other products that glorify and illuminate our times, there would be no problem. The ability to invent and produce such products is part of our technology, and in modern-day terms, the sky is no limit. These things are contributions towards fulfilment of our biological demands for nurture and comfort, and have little influence on the intellectual and ideological side of our lives. But, as pointed out at the beginning of this chapter, science is an intellectual tradition, not merely a technological development. Science is a body of knowledge; not all knowledge, but a particular kind of knowledge concerning the structure and operation of the world around us. The nature, structure, and limitations of science will occupy our attention throughout most of this book. For the present, let us say that science is a kind of knowledge.

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Vitamin pills, television, radar, and hybrid corn plants are not science. They are simply the results of the particular uses that have been made of scientific knowledge. These things, and thousands of others, are the fruits of science; they represent ways that science may be used within our society toward solving problems and making life easier

and richer. This distinction between science and its applications is quite clear if we keep in mind that the uses made of any bit of scientific knowledge are not the inevitable results of that knowledge. The way science is used is determined by what sort of a culture we, as a society, strive to build.

I recently heard a man refer to the future with despair because, as he said, 'Mankind doesn't stand a chance to last very long, since science keeps figuring out new ways to kill more and more people.' Nations, not science, build fiendish machines to slaughter the citizens of other nations. The physical knowledge of matter and energy, even though essential to the invention of the atomic bomb, will not explode. The now famous equation $E=mc^2$ (the energy in a body is equal to its mass multiplied by the square of the speed of light) is in itself quite harmless. If the world's societies were dedicated to peace, the powerful forces predicted by that equation would be used for the production of power, for scientific and medical research, and for moving mountains. But the direction taken by human societies has resulted in using the knowledge of science to build engines of destruction.

It hardly needs pointing out that the credit side of the ledger is also heavy with achievements. Mankind has greatly benefited from the application of science to the problems of living. But these accomplishments, too, have come through society's particular uses of science. So, in the final analysis, science as such is not responsible for either H-bombs or vitamin pills, but it is fully responsible for the knowledge necessary for their invention. Whether the sum total of scientific application will add up to the benefit, detriment, or destruction of the human race will depend on what we want as a society, and on what we are forced to do by other societies. In this age of science,

science is indeed a powerful tool for the shaping of a civilization. But the sculptor, not the chisel, must receive credit for the statue.

The separation of science from its practical applications (applied science) is by no means as simple in actual practice as it is on paper. The ivory tower is not usually very far from the market place. The situation becomes quite complex because of the pressures exerted on scientists by social groups. Since science is knowledge concerning the phenomenal world and its operation, it is to be expected that groups of people with different interests are going to encourage development of those areas of science useful to their problems. This results in unequal growth among different scientific fields. It also has the important effect of causing the accumulation of purely scientific knowledge to tend to move in directions dictated by applied science.

In the United States, scientific research is very well financed. Philanthropic organizations, groups devoted to promoting disease research (cancer, polio, etc.), governmental agencies, and industrial interests all invest large amounts of money in scientific research. This is not done simply to give scientists employment; research is financed because some return is expected in the form of useful information. In the case of industrial-research support, the hope is for immediately lucrative information. In most other cases, a long-range viewpoint is maintained. The expectation is that the research will contribute to basic information required for the eventual solution of some particular problem. This means that most scientific work is directed toward two goals simultaneously. One goal is in applied science, and the other is in so-called 'pure science', or knowledge simply for the sake of knowing.

This double-goal effect is well illustrated by the type

of research which is sponsored by organizations devoted to combating different diseases. They are very much interested in promoting research that might lead to solutions to practical disease problems. They realize, however, that the practical problem may be solved only through a fundamental understanding of all of the factors involved. For instance, in research on cancer, a large number of projects are devoted to the study of normal body cells and how they function. An understanding of normal cell functions just might yield rich returns if a comparison of normal cells with cancerous cells should give us some clues as to what causes a cell to become cancerous. Only then could a means be found to prevent the formation and spread of cancer cells. This sort of example may be multiplied many times in a wide variety of scientific fields.

But research works the other way, too. Many discoveries of real scientific importance have been made during the course of research on the solution of practical problems. A great many examples, both ancient and modern, might be cited to illustrate this point. In 1922, for instance, F. G. Banting and C. H. Best isolated the hormone insulin in almost pure form and discovered something of its importance. Working at the University of Toronto, they had been definitely and consciously concerned with the practical problem of diabetes. Their isolation of insulin was of great medical importance, for insulin has proved invaluable in the clinical treatment of diabetes. As a result of the work of these two men and those who have carried it forward, many times more human lives have been saved than were snuffed out by an atomic bomb dropped one August morning over Hiroshima. The work on insulin was also of purely scientific importance, in that it added much to our understanding of physiology. Literally thousands of other examples might be pointed out in which

information obtained during the course of practical research has increased the size and scope of the body of knowledge we like to call 'pure science'.

Perhaps even more numerous are examples of scientific work leading to practical applications never dreamed of by the scientist who made the original discovery. One of the more interesting examples along this line is that of the work of Luigi Galvani. Galvani was an Italian biologist of the eighteenth century. He was interested in muscles and what makes them work. He used the big leg-muscles of frogs for his experiments. One day, while making a dissection in a room where another man was operating a static electricity machine, he noticed an odd thing happening. Whenever the static machine was made to give off a spark, the leg muscles of Galvani's frog would jump. This aroused his curiosity more than just a bit, and he began to study this strange effect.

Out of Galvani's intensive study of muscles and electricity came the knowledge which allowed Alessandro Volta to invent the electric battery. Galvani certainly had no inkling that a battery would be produced from his being intrigued by a twitching muscle. It is also certain that Volta had no idea of the multitude of practical applications that would be made of his battery. The names of these two pioneer scientists are known to everyone who speaks of voltage or galvanized metal, so basic was their work to our knowledge of electricity.

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Before going on to other aspects of science, another factor needs to be examined. That factor is the scientist. A scientist is a man, and he is susceptible to all the shortcomings, aspirations, frustrations, and confusions which other men experience. He is not an evil genius or bumb-

ling neurotic, as depicted by most novels and films. To be sure, some might be called geniuses, but most are neither more nor less than intelligent people who are curious to learn more about the strange and wonderful world in which we live.

Each scientist is trained in the methods of science, and is involved in laboriously and cautiously filling in details of knowledge in his specialized field. Great discoveries do not emerge automatically from such detailed information. As we shall see later, new concepts come as the result of detailed knowledge plus the tireless efforts of one or a few scientists of greater than average insight.

If a scientist is working on a problem because of curiosity as to the explanation of some natural phenomenon, he is functioning purely as a scientist. If, on the other hand, he is studying the phenomenon in an effort to find the answer to a practical problem, a problem posed by our society, he is functioning as an applied scientist – a technologist. The difference between the two is largely a state of mind, and no sharp distinction is possible. Nearly all scientists function as technologists at least part of the time. And in their day-to-day living they are not something set apart from the rest of mankind, but are just normal members of the human race.

We see, then, that science is different from the fruits of science. The difference is the difference between knowledge and the use of knowledge. Scientific knowledge is used by our society to solve some of its problems and to attain some of its goals. This use we call applied science. When a group of people believes that a particular problem might be solved most efficiently through the methods and knowledge of science, research toward that goal is begun. Such work may be strictly technological – that is, practical use of existing knowledge. Or it may involve new explora-

tions of thought and experiment which will, perhaps, contribute to both an immediate problem and a scientific concept. In our complex civilization. both paths are being followed. But it is essential that we realize that it is we as a people, as a society, who determine the uses to which science is put. Likewise, we as a society determine the general direction of the advance of scientific inquiry. Science is a mighty tool, a gigantic weapon. But it is a two-edged weapon; it can be used for good or for evil. Through our use of science, we can free and elevate the human race, or we can utterly destroy it.

Applied science is related to what at the outset of the chapter was called our biological demands on nature. Pure science is much more than that, however, for it is an interpretive body of knowledge. As it represents an interpretation of our universe, it is an intellectual tradition. Science is man's most successful intellectual adventure, and through this accumulated heritage of thought and method, the human mind has probed deep into the mysteries of the universe.

Although nature is a challenge and scientific research a great adventure, in modern civilization science is becoming increasingly important as an ideological force. As the earth becomes more crowded and as methods of communication and retaliation improve in speed and accuracy, the planet seems to become smaller. Although our planet seems small, the horizons of the world we know and would like to understand and dominate become broader and broader. This makes the planet earth seem still smaller. Our growing science and our dwindling natural resources make foreseeable a day in which our earth will no longer be adequate. In the present day, problems of survival are becoming more acute; not individual survival, but national survival. Problems of nation

cooperating with nation to maintain a livable world are becoming screamingly urgent.

The problem of men and nations learning to live with other men and nations in peace and understanding involves ideologies. If we do not agree on the position of man in the universe, his destiny on earth, or his individual value, we cannot live in lasting harmony. We may adopt expedient policies to allow peaceful 'coexistence' because of mutual fear of each other. Such policies can be but temporary and result in nations that are armed camps, living in an atmosphere of fear and suspicion. Areas of mutual misunderstanding are not clarified by either wars or armed peace. The ideological concepts held by a people determine the goals, the purposes, the values to which that people is dedicated. The earth's community of nations is split into armed camps today because of conflicting ideological beliefs. This is the great threat to the survival of our civilization.

Our advancement in science has far outstripped our social and spiritual progress. If our social and spiritual traditions could be coordinated with or incorporated into our scientific tradition, perhaps a balance could be restored. With an ideology which included science as the basis for solving human problems, the future might be faced with peace and assurance. The tradition of science is held by most nations and commands respect among all peoples. Can we, then, formulate a common ideology from the methods and content of science? The goal would be a scientific philosophy of life which would be acceptable to everyone because it would serve as a common denominator for the ideologies of different peoples. Whether or not this is possible rests, ultimately, on whether or not all human thought can be made to conform to the conditions of scientific knowledge. Can we answer the basic

questions as to man's position and purpose in the universe through science? We certainly do not now have the scientific knowledge needed for such a grandiose undertaking. The question is whether such a philosophy is a goal toward which we can strive, or something which will always elude us. To answer this question, we must understand the nature and meaning of science. In the following chapters we will explore the structure of science. We will examine the assumptions that act as its foundation. We will survey its limitations, and try to appraise its potentialities. Only then will we be in a position to understand science as a force in shaping the thoughts and philosophies of mankind. We must learn to recognize what is science and what is not science. Toward that end, this small volume has been written.

2

WHAT IS AN EXPERIMENT?

In the first chapter it was asserted that science is a kind of knowledge which is a very useful tool in solving the technical problems of industry, agriculture, warfare, and medicine. Science has become a powerful force in shaping and building the structure of our civilization. But the shaping and building must be according to the blueprint formed by our morals and goals; they do not automatically emerge from scientific knowledge. To understand the width and depth to which science can be applied to the material and spiritual problems that confront individuals and nations requires an understanding of what science really is.

The word *science* comes to us from a Latin word, *scire*, which means 'to know'. Loosely, then, science is simply what we know; the sum total of all human knowledge. But the definition of science as all knowledge would not be a workable one, for it is obvious that there are different types of knowledge. The kinds differ according to how the knowledge was obtained, and also according to what frame of experience it fits. What we know of the arts, literature, law, religion, and technical know-how, are more or less separate funds of information. They have little to do with what we commonly call science.

Knowledge is gained in different ways. Some things we know from our particular experiences as individuals – things that we have learned the hard way, as it were. Some knowing comes from the experience and thought of others, through social contact, reading, and the traditions

of education and religious training. Some things which we say we know apparently arise from within our minds, internally or intuitively. Intuitive knowledge is little understood, but it appears to come from the totality of one's experience and thought. Different sorts of knowledge represent different aspects of our ideas of the many-faceted world in which we live.

Science is also called *natural science* to distinguish it from other branches of learning. And it is only in this sense that the word science is used in this book. Science is, indeed, concerned with nature – that is, with knowledge of the characteristics and operations of any and all natural things and happenings. Science is much more than knowledge of elusive high-speed subatomic particles, despite the recent emphasis on that branch of physics. Science embraces all of nature, and expresses our best ideas of how natural phenomena are related to each other and are to be woven into what is called the universe.

Science has many characteristics, and to understand what science is requires a detailed examination of these properties and peculiarities. Let us start our examination by investigating the methods by which scientific information is gathered. A number of writers have asserted that science is really only a method – the scientific method. Such a definition is an oversimplification, but it is certain that the scientific method plays a large part in determining the nature of scientific knowledge.

When the non-scientist thinks of scientific research, he usually visualizes a laboratory containing a lot of complicated glassware and much mysterious and costly apparatus with many dials, switches, and blinking lights. Here the white-jacketed scientist and (according to the cinema) a pretty blonde assistant perform experiments which unlock the secrets of nature and make the scientist

famous, unless his experiments blow up the laboratory. Trimming away the technical equipment, and the white jacket, and (regretfully) the pretty assistant, leaves only the man and the experiment. In the man and the experiment lies the key to the scientific method. Of the man, we will have much more to say from time to time. It is the experiment which we want to look into now.

Offhand, one would think that an experiment is a simple thing – just a matter of trying out some idea to see if it works. It is that simple, except for this thought: how do we select an idea to be tried, and how do we know that an experiment will give us any information on that idea? Important as it is in the methods of science, the experiment is always preceded by two important steps and followed by still another.

The beginning, the first step in the scientific method, is one of simple observation. An observation is made of some phenomenon, one of nature's hard facts. A bird flying, a bee collecting pollen, a man dying, these are facts. It is with such facts that a scientific investigation must begin. It is on a foundation of such facts that science is built.

We cannot explore the intricate details of something we cannot even observe by one means or another. In some branches of natural science, observations constitute the bulk of the knowledge. Anatomy, for instance, is mostly observational and descriptive. Only when combined with physiology and biochemistry does it become experimental. Taxonomy is the branch of biology concerned with describing, naming, and classifying all the different kinds of plants and animals. Such a branch of learning is almost entirely descriptive. It has been only in recent years that taxonomy has developed experimental aspects. Science begins with *observations.*

From the observations we make, we formulate ideas concerning the nature of the world in which we find ourselves. Such ideas may be very fanciful, but unless there is some means of testing them, one interpretive idea is about as good as another. In scientific research, the first step beyond observation is a tentative idea on how such observations are to be interpreted. The untested idea or scheme is called a *hypothesis*.

The amazing strength of the scientific method lies in the system used to test the hypotheses that are inspired by observations. The testing is by experiment, but the experimentation must be carefully thought out and designed, so that the results of the experiment can be interpreted in a minimum of different ways. Such an experiment is called a controlled experiment. Gaining an appreciation of science requires an understanding of the dependency of science on controlled experiments. For it is only through controlled experiments that we are able to advance and to correct errors that creep into accepted scientific knowledge. The best way to learn about the nature of a scientific experiment is to explore an example. The flight of bats should serve as an interesting experimental subject.

The bat is the only known mammal that is a true flier. Some other mammals – such as the flying squirrel – can glide, but only the bat flies. Almost everyone has seen the common brown bat as it wends its irregular fluttering flight in the failing light of dusk. The most common species is little bigger than a mouse, and is sometimes known as a 'flittermouse' or a 'fledermaus'. From common observations of bats by many people over hundreds of years, we know that bats are expert fliers, catching flying insects and eating them on the wing. And yet, it is also known that they have very poor eyesight, a fact which has

given rise to the expression 'as blind as a bat'. Bats are famous for their visual shortcomings. But then, they fly only at night when it is too dark to see anyway. They spend daylight hours hanging upside down in a dark cave or hole, wrapped up in their own thin furry wings, presumably sleeping.

If bats fly at night and eat only flying insects, how can they catch the insects if they cannot see them? And, being blind as bats, what prevents their crashing into things like trees, rocks, and buildings? It should be possible to set up experiments which would yield some information on how bats navigate with the skill that they show.

It would be very difficult to experiment with bats which are flying around outside. The first thing that we must do, therefore, is to capture some bats, and then experiment with them under more confined conditions. It is especially important that our experiments be conducted under conditions which are standardized. Standardized conditions will allow us to make only one experimental change at a time, and to measure just what effect such a change has on the behaviour of the bats.

After obtaining some bats, we must set up the conditions under which our experiments are to be run. A large, bare, windowless room would serve our purposes quite nicely. In such a room some obstacles must next be installed. Heavy wires stretched from wall to wall and from floor to ceiling at various angles will certainly increase the hazards of aerial navigation within the room. Such a type of obstacle has the advantage of being uniform in size, and the number of them in the room can be increased or decreased very easily. However, we must also have some way of knowing when a bat smashes into, or even touches, one of the wires. This may be accomplished easily by running the wires through the walls and connecting them

to signalling devices. We can hook them up so that when something touches a wire inside the room, a bell rings, or a light flashes, or a mark is made on a piece of paper.

Suppose that we fix up such a room, and install a hundred or so of such wire obstacles. Each wire is connected to a recording device which is so sensitive that it will distinguish whether the wire was firmly struck or only lightly brushed. We now release some bats in the darkened room and watch our recording devices. The recording instruments show that occasionally a bat barely brushes one of the wires. Only exceedingly rarely does a bat strike a wire with any appreciable force.

We are now ready to run a controlled experiment. Up to this point we have not run an experiment; we have only set up the necessary conditions. Just as it had been observed that bats do not collide with obstacles in their normal environment, we have now observed that bats do not collide with wire obstacles in the artificial environment we have created. What keeps them from colliding with the wires is still as mysterious as before, however. What has been accomplished thus far is the establishment of controlled conditions under which experimental changes may be tested easily and one at a time.

If experiments are now to be run on how bats avoid collision with wires in a darkened room, a hypothesis is needed. Some tentative idea is needed as a starting-point. In our ordinary experience, animals avoid collisions by keeping their eyes open and watching where they are going. It seems unlikely in the case of bats, but let's test the idea anyway. Perhaps bats have poor visual perception in the daylight, whereas under night conditions their vision is fantastically sensitive. The hypothesis to be tested is, therefore, that under our experimental conditions, the eyes of the bat are instrumental in preventing colli-

sion with wire obstacles. We are now ready to run a controlled experiment.

A normal bat is allowed to fly through the wire obstacle course, and our recording instruments show that it did not run into any wires. We now know that this particular bat can normally avoid smashing into the wires. Its record of normal performance acts as the control for the next part of the experiment. Taking the same bat, we mask its eyes with tiny patches of black tape. Once again it is made to fly in the wire-filled room. Once again, it wings its way about the room without collision. Since its performance blind was the same as when in a normal condition, we must conclude that the results we obtained did not seem to indicate that the eyes were important to the bat's flying efficiency. The hypothesis that we set out to test was not supported by the results of the controlled experiment we ran.

However, another factor must also be taken into account. That factor is chance – just plain luck. Perhaps by blind luck the bat managed to fly between all the wires, in spite of having its eyes covered. In any one experiment, we can never be sure that the results of the experiment are not due to simple chance. This possibility is greatly reduced, but never completely eliminated, by the simple expedient of running each experiment many times. Only after conducting the blinded bat experiment several times can we be reasonably sure that as we tested the bats, the eyes did not function to prevent them from colliding with the wires.

From the results of our experiments some information was gained, even though the tested hypothesis did not turn out to be correct. To the original observed fact that a bat can fly through a room containing obstacles without collision, we may now add the observed fact that it can

do it with its eyes shut. We still do not know how the quaint little creature accomplishes this amazing feat, but we know that we must look to means other than the eyes. The question is what to try next.

The ears of a bat are large and are extremely well developed. From the highly developed anatomy of the ear, the bat might be expected to show very good sensitivity to sounds. Although it seems unlikely, let us set up the hypothesis that the ears are in some way involved in the wee beast's aerial dexterity.

Again we turn to the controlled experiment to test our idea. Once more we start the experiment with a normal bat. And once more it runs the maze of obstacles without touching a wire. Then the ears of the bat are carefully and gently plugged with bits of soft wax. The bat is returned to the experimental room and is released. Immediately a surprising thing happens; the recording instruments connected to the wires begin to record hit after hit. The bat can no longer locate and avoid the obstacles, but strikes wire after wire in a completely disorganized flight.

Of course, the experiment is repeated many times, using different bats and different means of making the ears non-functional. The results are always the same. Without fully functional ears, the bat is unable to avoid collisions. The results of these experiments definitely supported the starting hypothesis. We now have good reason to believe that the ears are in some way involved in the bat's amazing flight ability.

But how can a bat hear a wire? What possible connexion can there be between hearing and avoiding collision with a silent inert object such as a wire? Normally a bat hunts and catches flying insects. Anyone who has heard a bee, a fly, or a mosquito is well aware that insects

make a flight noise. It seems quite reasonable to suppose that the bat may hear the flight noise and 'zero in' on it to capture the buzzing bug. But here in our experiments we are faced with the necessity of explaining the role of the ears in flight ability, not just hunting.

If a person picks up a bat, it usually makes a squeaky little noise. There is an old saying to the effect that only a young person can hear the squeak of a bat. The bat's squeak is very high pitched, and may not be heard by a person who has reached the age where his auditory range has begun to decline. Although the bat utters its shrill cry when handled, does it fly silently? This can be determined easily by bringing sound amplifying and recording equipment into our experimental setup. With such equipment, we can 'listen in' on our experiments. With no bat in the room, we find that all is silent; the wires do not make any detectable noise. When a normal bat is released in the room, the quiet is broken. As it flies through the maze of wires, it squeaks very frequently and regularly.

Does the bat's shrill cry have something to do with the uncanny flight ability, Once again, we turn to a controlled experiment for information. This time the hypothesis is that the sound produced by the bat plays some role in preventing collisions in flight. Once more, bats are checked for normal performance. Then, with jaws taped shut, the bats are released in the experimental room. The muted bats collide with the wires. Their flight is as disorganized as it had been when their ears were plugged. The results support the hypothesis, and the conclusion is reached that the vocal efforts of the bat have a real importance to its flight behaviour.

On the basis of the information we have gathered, is it possible to construct a logical and consistent answer to the question 'How does a bat avoid collision while flying?'

A number of observed facts must be taken into consideration:

1. Normal bats can avoid collision while in flight.
2. Normal bats utter frequent shrill cries while in flight.
3. Blinded bats can avoid collision while in flight.
4. Deafened bats do not avoid collisions.
5. Muted bats do not avoid collisions.

Any interpretation we make, any answer we formulate for the question which we originally posed, must be consistent with each and every one of these observed facts. The first one, namely, that bats can avoid collisions, posed the original question. The other four observed facts constitute what we have been able to add to the original observation by means of a few simple controlled experiments.

The bat's dependence on both voice and ears for skilled flight suggests that the bat itself produces the sounds which guide it. Several examples of man-made equipment operating on this principle immediately come to mind. Echo-sounding equipment has been used on ships for many years for the purpose of measuring the depth of the water under the ship. A sound signal is sent through the water straight down from the ship. The length of time required to get an echo of that sound off the ocean bottom is, of course, dependent on how far the sound has to travel. The length of time required for a sound signal to make the round trip from ship to bottom and back to ship will be in proportion to the depth of the water.

Submarine-detecting equipment, called sonar, operates on the principle of locating underwater objects by bouncing sound waves off them. By measuring the time it takes to get back an echo and by measuring the angle from

which the echo comes, the submarine may be located precisely.

A logical interpretation of our bat data would be that the bat flies by a biological equivalent of sonar. Sending out short shrill cries, it adjusts its flight direction and behaviour according to the echoes it receives from anything – prey or obstacle – which happens to be in the vicinity. This explanation is consistent with all of the observed facts. It also has the added appeal of being consistent with what is known of the physics of sound waves.

The interpretation we have made concerning the flight of bats does not settle the matter once and for all. Further experiments might yield results making it necessary to reinterpret all of the evidence. Where we leave the problem, however, the most logical and consistent explanation of bat flight is that bats are guided by echoes of the sounds they produce. In just a few experiments, we have found an animal that is apparently guided almost entirely by sound.

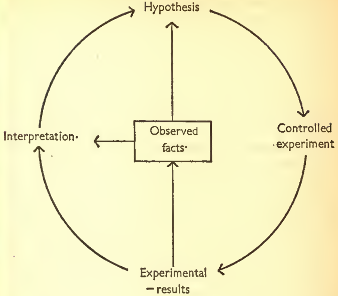
At this point, there is a temptation to go far beyond the data we have. One is tempted to speculate on what the bat experiences, how it lives in a world of echoes, how it identifies objects by how sounds bounce off them, how it is unaware of the world of colours and lights, and how it 'sees' with its ears. Such temptations must be resisted. They must be resisted because we know nothing of the feelings, impressions, and mental experiences of bats. In our experiments, we have dealt only with how bats behave. To speculate on these other matters is to ascribe human characteristics to the bat and to try to put our own minds and personalities in the bat. This is called *anthropomorphism*, and is one of the cardinal sins that may be committed by a scientist. Avoiding anthropomorphism is sometimes difficult, nevertheless. In the interpretation of

experiments, in the simple description of behaviour, even in the definition of the terms we include in a scientific vocabulary, avoiding anthropomorphism is far from easy.

The bat experiments illustrate many of the features common to all scientific research. What is to be learned from them, as far as this chapter is concerned, is not what we think we know about how bats fly. What we are interested in is the structure of the scientific method, and the sort of knowledge we gain from it. Not all experiments are as simple and direct as the bat experiments, but the basic design is nearly always the same.

We must always start with some observations of facts. These observations may concern any natural happening – in a forest, in a zoo, at sea, or in a laboratory experiment – anywhere. The observations must next inspire an interpretive idea or hypothesis in the mind of someone. The hypothesis must have one vital characteristic – it must be testable by controlled experiments. However fantastic it may otherwise be, if it is testable it is legitimate. It hardly needs to be pointed out, however, that many hypotheses popping into an investigator's mind are tested only mentally, and are discarded as being inconsistent with the observed facts.

The hypothesis selected for testing may be just one of several possible. The experiments run must be controlled as rigidly as possible. The ideal situation is one such as in the bat experiments – experimental conditions so well defined that it is possible to vary only one thing at a time. The results of the experiment are another set of observed facts. These new facts, added to the original observations, may force us to form a new interpretation, and, in turn, give rise to another hypothesis to be tested. Diagrammatically, it can be put this way:



Thus, as more and more observed facts are obtained under different conditions, particularly controlled experimental conditions, the better are our chances of arriving at the understanding we seek. In the problem of the flying bats, it was only after amassing the results of several experiments that we arrived at a solution. The solution we found was both logical and consistent with all the facts known up to that time.

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As more information is accumulated, our knowledge grows and, therefore, our theories and ideas change. Science is sometimes accused of being unstable – 'Scientists cannot make up their minds. What they say is true today,

they may deny tomorrow.' This supposedly deplorable condition is actually one of the great strengths of science. Our ideas of nature – how it works, how it is constructed – grow in stature and strength as more and more observed facts can be fitted into our man-made schemes.

Many examples of how we must change our ideas as we find more facts that must be fitted in can be found in the history of science. A very good instance is found in the early days of experimental botany. In about 1640 a Dutch biologist named Jean-Baptiste van Helmont ran an experiment which led him to the conclusion that the leaves, bark, and wood of trees are made from nothing more than pure water! His experiment was very well designed and carried out. He took a very large clay pot and filled it with exactly 200 pounds of thoroughly dried soil. Then a small willow tree was planted in the pot and was watered well with pure distilled water. The clay pot and tree was set outdoors in the weather, where trees normally grow. To prevent dust and dirt and debris from getting in, the soil around the tree was covered with a sheet of iron, perforated with many small holes.

For five years the tree was carefully tended. Van Helmont watered it with distilled water during the dry summer seasons, and swept away the fallen leaves in the autumns. Nothing but distilled water from a watering-can, and rain (which is also distilled water), was ever allowed to fall on the soil around the tree in the clay pot. The little willow tree grew normally, and after five years van Helmont decided that it was time to end the experiment.

Being careful not to spill and lose the soil in the big clay pot, he cautiously dug the tree out. After he had painstakingly brushed all the soil off the roots back into the pot, he weighed the tree. Where he had planted a

willowy shoot weighing only 5 pounds, he now found that he had harvested a tree 169 pounds in weight. Not even counting the many leaves that had dropped off during the past winters, his tree had gained 164 pounds of roots, trunk, branches, bark, and leaves.

Where had all this plant come from? From the soil perhaps? Jean-Baptiste van Helmont now turned his attention back to the clay pot full of soil. He removed all the soil from the pot. The soil was again thoroughly dried and then was weighed. It weighed almost exactly 200 pounds. To all appearances, it was the same 200 pounds with which he had started the experiment five years earlier. Now, van Helmont was sure that nothing had been added to the soil except water. He therefore concluded that 164 pounds of plant substance had been formed from water alone. He had originally considered that there were only three possibilities: either the plant grew from the substance of the soil, or it grew from water, or partly from soil and partly from water. His experimental results were conclusive; there was no loss of soil, and therefore the willow tree was formed from only the water.

It is all too easy now to look back over the years to 1640 and see the gaps and errors in van Helmont's experiment and conclusions. Our knowledge of plant physiology and chemistry has grown tremendously since 1640. It was not then known that plants manufacture sugars and a whole host of organic substances by a process known as photosynthesis. In photosynthesis, plants make simple sugars by using the energy of sunlight to combine carbon dioxide from the air with water from the soil. From these simple sugars, other compounds are made by the plant. Neither was it known in van Helmont's time that bacteria in the soil capture nitrogen from the air, and it thereby becomes

available to the plant by absorption through the roots. The plant requires nitrogen in order to make proteins. Nor did van Helmont know that plants absorb very small amounts of some minerals from the soil.

Indeed, this brief statement of twentieth-century knowledge of plant growth contains words, ideas, and whole fields of research little dreamed of by Jean-Baptiste van Helmont. The existence of photosynthesis was not suspected until 1727. Air was thought to be a single element, and it was not until the work of Joseph Priestley in 1772 that it was realized that there could be more than one kind of gas. So the existence of oxygen, nitrogen, and carbon dioxide was completely unknown to van Helmont. It was 1796 before it was found that carbon dioxide was in any way involved in plant metabolism. Not until 1840 was it known that plants may obtain nitrogen compounds from soil micro-organisms. Bacteria were unknown in 1640, and were not discovered until 1683.

In our present brand of scientific research, we cannot make allowance in our experiments and conclusions for what may not be known for another hundred or so years. Obviously, neither could van Helmont. As we learn more, we can correct our concepts so that they fit our observations better. It should be pointed out, however, that van Helmont was still about ninety-five per cent correct in his conclusions. About ninety-five per cent of a plant is derived from water. But, unfortunately, the other five per cent is the most important part of the plant.

The experiments with bats and willow trees are quite typical scientific experiments. From these two examples, there are a number of things we can learn about this body of knowledge we call science. It has already been pointed out that it is about things that happen in our world – either occurring naturally or by our efforts. We have also

seen that science is tested knowledge. And through this continuous sifting and winnowing, we strive to come ever closer to the truth.

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There are also other characteristics of science that are shown by the examples we explored. Two of these characteristics are really nothing more than very simple and, perhaps, naïve assumptions. It is a common idea that 'science is based only on facts, not assumptions'. The truth is that science, like any body of knowledge, is based on some assumptions. We will encounter some of them many times in our exploration of science. One assumption clearly shown in the experiments with bats and willow trees is so simple that it is usually overlooked – the assumption that *nature is understandable.* This is nothing more than an assertion of faith that the phenomena making up our world are not so complicated or mysterious that they cannot be understood. This is actually a very ambitious belief, and we will meet it again in a later chapter. But without this assumption, we would hardly be likely even to undertake investigations of any sort.

This leads us to the second important scientific assumption. This one is a simple belief in *cause and effect.* To put it more exactly, every observable phenomenon is held to be the result (effect) of definite and measurable causes. This is a simple faith in an orderly nature.

A faith in cause and effect is a faith shown by everyone. Without it the world would seem completely chaotic. If, on a warm summer evening, you switch on an electric fan, you expect it to start operating. And once operating it will create a pattern of circulating air. As the air stream passes over your perspiring brow, the rate of evaporation will be increased. Since evaporation entails absorption of

heat, the fan's running results in your feeling cooler. All of this is a chain of events, described in terms of cause and effect.

Suppose, on the other hand, that the fan does not operate when the switch is turned on. You do not suspect that nature has changed; you assume that there has been a break somewhere in the chain of events which should result in a whirling fan. Accordingly, you look for a power failure, a broken wire, a broken switch, a burned-out motor, a blown fuse, and so on. Suppose the fan operates, air circulates, but you do not feel cooler. You do not blame it on an unstable or whimsical nature. You conclude that the relative humidity in the room is too high, and you think of replacing the fan with an air conditioner. Thus it is with us all; we always look for natural explanations for things that happen, or fail to happen, as we think they should. We cannot believe that phenomena occur in a disorderly, haphazard, or inconsistent manner.

If, when the electric fan was turned on, we could not predict from one time to the next whether or not it would operate, or which way it would turn, or whether air would be moved, or whether evaporation would occur, and the same sort of uncertainty was associated with all of our different attempts to do things, life would be impossible. Science would be unthinkable. If cause and effect relationships which were apparent at one moment were completely upset in the next moment, any effort to understand and exploit the world about us would be fatally frustrated. Without an underlying faith in natural consistent behaviour in which causes as well as effects are detectable, scientific progress would be impossible.

This assumption of the infallibility of cause and effect may lead us to something of a quandary. For if any occur-

rence is the result of some definite causes, are not these very causes simply the effects of still more causes, and so on down an infinity of previous causes? It would seem so, and for a long time such an endless chain of cause and effect was considered inescapable. This led to the often-quoted statement by a French scientist of the eighteenth century, Laplace, to the effect that a perfect intelligence, knowing the position of every particle in the universe would also know the entire history and future of the universe. More recently, however, it has become apparent that strict cause and effect may not always hold, and that sometimes we must deal with pure chance. More of that in another chapter. It is quite certain, however, that within our every-day experience and within most areas of science, a belief in cause and effect is both justified and fruitful.

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One of the popular notions about science is that many scientific discoveries have come about accidentally. It will be worth while to look into this idea, to see whether or not discoveries can be accidents. There are many examples of 'accidental' discoveries, and one of fairly recent times is the discovery of penicillin.

Penicillin is one of the modern miracles wrought through the application of science. The 1928 discovery of penicillin is a story which involves a culture of bacteria, a mould spore, and an observant man. The man was an English bacteriologist, Sir Alexander Fleming. He was doing some work which involved growing cultures of bacteria on agar in shallow, covered glass dishes. Agar, by the way, is a jelly-like material which is obtained from seaweed, and is widely used for growing moulds and bacteria in the laboratory. The bacteria multiply rapidly under such conditions, and the surface of semi-solid agar

soon becomes covered with a thick layer of bacteria. Of course, elaborate precautions must be taken to keep the cultures pure. Bacterial and mould spores that are forever drifting about in the air must be excluded. Any cultures becoming contaminated with such microscopic intruders are usually worthless for experimental purposes.

Despite the usual precautions, a mould spore found its way into one of Sir Alexander Fleming's cultures. Thus it was that when he inspected his culture dishes, he found a thriving colony of the common green bread-mould *Penicillium* in one of them. The whitish layer of bacterial growth had spread over the agar, but in the centre there arose a little green hill of *Penicillium.* A single mould spore had fallen there, germinated, and begun growing to form a colony. Such an occurrence is not at all infrequent in bacteriological laboratories, and the contaminated culture is merely to be discarded. But Fleming observed something a bit peculiar about the ruined culture. Bacterial growth covered the surface of the agar, except for a wide zone surrounding the spot of mould. Why should the bacteria fail to invade and thrive in the immediate vicinity of the mould colony? Perhaps the growing mould secreted a chemical which killed the surrounding bacteria. He tested this hypothesis experimentally, and found that his results were consistent with the idea. The bacteria-killing chemical was eventually isolated and was named 'penicillin' in honour of the lowly green mould which produced it. Thus penicillin was discovered, and a field of study – antibiotics – was opened for intensive exploration and development.

The discovery of penicillin is often ranked among the so-called accidental discoveries in science. The only element of accident in the story was the accidental contamination of Fleming's culture of bacteria. But that sort of

thing is very common; it happens every day in laboratories the world over. Fleming's noticing the zone of no growth around the mould colony was no more an accident than is any other observation. Louis Pasteur, the renowned French scientist, once said that chance favours only the prepared mind. The possible significance of the bacteria-free area was noticed by the prepared mind of Sir Alexander Fleming. To an untrained, unprepared mind, it would have passed unnoticed or been dismissed as having no significance. The story resolves itself into the familiar four steps of the scientific method – observation, hypothesis, experiment, and conclusions. There is no accident there.

It is doubtful that any scientific discovery has been by accident. To be sure, an observation may come as the result of a chance happening. But the observation is not an accident; it is the product of a prepared mind. It is of value only for the hypothesis, experiment, and conclusions which follow it. Thus, accidents have little to do with science.

3

WHAT IS A THEORY?

KNOWLEDGE of bats and willow trees and moulds may be very interesting, but where does it get us? Controlled experiments may be important and simple in concept – a matter of testing one idea at a time – but is this a weapon with which we can attack anything really big or complicated? Can the problems of life and universe be solved with such a puny tool? These are important questions, and finding the answers to them requires that we explore still further into the characteristics of science.

Isolated experiments on particular and simple hypotheses would lead only to isolated and disconnected bits of information. If this were the only goal, science would hardly be worth the effort. The goal is much more grandiose, however, and the aim is to build large theories from many small bits of tested information. One is reminded of an old fable about a man and his seven sons. It seems that the seven sons were forever fighting and arguing among themselves. This annoyed the old fellow very much, and he sought a way to put an end to the discord. Calling the boys together, he handed them a bundle of seven sticks and asked if any of them could break the bundle in half. Each tried and each failed. Then the father separated the bundle and easily broke each stick, one at a time. The moral is obvious; there is great strength in numbers when united. So it is also with pieces of information.

If the observations and results gleaned from many experiments from different laboratories reflecting the efforts, thoughts, and techniques of many different scien-

tists can all be brought together, an interpretation of strength and beauty may result. By such means a scientific theory or concept is formed. Of course, it is obvious that a theory must be consistent with all the experimental data. Using observations and experimental findings as bricks, we build the structure of a scientific theory.

A theory is our best idea as to how a group of separate facts are related to each other. Such concepts do not emerge automatically from observations and experiments, any more than bricks assemble themselves to form a house. Theories, like houses, must be built, and the style of architecture is dependent on the builder and the time and area in which he works. After many experiments have been run on different aspects of a particular subject, the accumulated information will enable one or a few scientists to propose a general theory bringing all of that information into one interpretation. A theory is a concept which unifies an area of scientific interest. It provides a single scheme of interpretation for a whole group of apparently disconnected facts.

Sometimes a new theory is readily accepted by other scientists as soon as it is proposed. But sometimes a new theory is challenged and a vigorous controversy arises. Battles are waged from the speakers' rostrums of scientific societies and from the printed pages of books and scientific journals. When such a controversy breaks out, there is a great scramble to run more experiments, testing new ideas and obtaining more evidence in support of one side or the other. Sometimes the issue is decisively settled. Sometimes the issue is not settled, but must be abandoned, pending the development of new methods and new evidence. The history of science is made quite exciting by the numerous turbulent controversies which have disturbed

its serenity. The birth of a new theory is seldom painless, but if our science is to grow and to have meaning, unifying concepts are essential.

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There is an incident in the history of biology that is well worth recounting here. It illustrates the sort of controversy that may attend the acceptance of a new and far-reaching theory. It also shows how biologists learned to use and understand the importance of controlled experiments. This incident was a controversy which lasted for about 200 years. During that extended time, biology as we know it today was being born, and was fighting for its very existence.

For the beginning of the story we must travel back in history many centuries to the times of ancient peoples. In antiquity, as in modern times, man tried to form a coherent and meaningful picture of his world. About him he saw a world teeming with living creatures. He also observed that certain animals were to be found most frequently in particular environments. That is, mosquitoes were seen emerging from ponds and stagnant water. Salamanders and frogs were to be found in the vicinity of muddy shores. Young turtles were to be observed coming up out of the ground. And so on. Thus, the concept arose that these animals were not only associated with their typical type of surroundings, but were actually created by their environment. Toads were thought to be generated by mud. Maggots were not just living in decaying flesh; they were produced by it. Mosquitoes were held to be formed spontaneously by stagnant water. All sorts of the lower animals were considered to be created continuously, on the spot, from non-living stuff – *a spontaneous generation of life.*

Belief in spontaneous generation of living things was widely held, and became imbedded in the written records of ancient cultures. The ancient Egyptians believed that honeybees were generated by the carcass of a bull. In a natural-history reference book written in Europe about 400 years ago, there were very detailed directions for producing bees from the corpse of an ox. For this purpose, a small house was required. This house must be fifteen feet high and fifteen feet long and fifteen feet broad. There must be only one door and four windows, one in each wall. Into this cube-shaped hut, an ox of about two years of age is led, and there beaten to death with clubs by two or three 'lusty fellows'. These lusty fellows must beat the ox until it is dead and its bones are broken, but they must not break the skin so that the animal bleeds. Then the nostrils and all other external openings of the ox must be stuffed with soft linen smeared with pitch. Next, some honey is to be poured on the floor around the animal, and the ox is turned 'face upward'. The house is then shut up for three weeks, after which time the door and windows are to be opened for a few hours, and then closed again. Eleven days later the house is again opened, and the room will contain a great swarm of bees. Of the ox, nothing remains but the horns, bones, and hair. The rest of the substance of the ox has been transformed into bees. The largest and most handsome of the bees were supposed to have been formed from the brains and marrow.

The insects that these ancient people saw around dead bulls, oxen, and others, were most probably not bees at all, but any of a number of flies which, at a superficial glance, resemble bees. This inaccuracy notwithstanding, the scientific name for the honeybee has come down to us as *Apis mellifera*. Apis is the Greek word for bull. This

name for the honeybee was not proposed at the time of ancient Egypt, but during the mid eighteenth century in Europe.

A procedure for creating mice is also found among the writings from Europe of the Middle Ages. If some rags and a few grains of wheat are put into a crock and sprinkled with a little water, adult mice will appear in a few days. According to some accounts, urine was called for instead of water. One was no doubt as efficient as the other. Many such recipes for producing living things are to be found in the writings of ancient scholars. So well entrenched was the concept of spontaneous generation, that it was believed by virtually all naturalists from the time of Aristotle into the latter half of the seventeenth century.

The idea of spontaneous generation was accepted without question, in spite of its drawbacks and inconsistencies. The higher animals and plants were known to reproduce themselves. Seeds of plants were, of course, familiar to all people. Sexual activity and birth processes were likewise familiar. The smaller animal forms, such as snakes, frogs, mice, insects, and so on were thought to be produced by both sexual and spontaneous means. Many plants were also thought to be produced both by seeds and by spontaneous generation. Only the smaller and more obscure forms of life were assigned to the category of the exclusively spontaneously generated. We see well enough, now, that this view is inconsistent, and that it is unscientific because it is based on simple observation rather than controlled experiments.

It is also a view that is not compatible with the basic ideas of natural unity. We must remember, however, that science in the modern sense did not begin to take shape until the seventeenth century. It is not surprising, there-

fore, that the whole concept of spontaneous generation was first challenged in that century.

Francesco Redi was a biologist who lived and worked in Florence during the seventeenth century. He became interested in the problem of the creation of organisms. He observed that if he killed a large snake and left it outside in an open box, maggots soon appeared and devoured the snake. As the maggots finished feeding and growing, they crawled away from the snake. Redi captured some of these mature maggots and put them in screen cages. After a week or so, they transformed into blowflies. The blowflies so produced were similar in every way to the flies that he had seen buzzing around the snake shortly after it had been killed. The blowflies were apparently of two species; one was a big black-and-white kind and the other a shiny green species. Both were very commonly seen in Florence and that part of Europe.

If it were true that maggots are generated by decaying flesh, then different kinds of meat should produce different kinds of fly maggots. This would seem a logical way to account for the multitude of different kinds of flies that were to be found in nature. Following this line of reasoning, Francesco Redi set out boxes containing the flesh of an amazing assortment of animals. His series included both raw and cooked flesh of oxen, deer, buffalo, lions, tigers, dogs, sheep, goats, rabbits, ducks, geese, hens, swallows, swordfish, tuna, eels, sole, and – as he put it – etc. Redi patiently watched what occurred in his boxes, and as the maggots became fully grown, he caged some. His caged maggots transformed into flies. The flies were the same kinds that he had obtained from dead snakes.

It was apparent to Redi that different kinds of flesh did not give rise to different kinds of flies. During the

course of his experiments, he made another very valuable observation. He observed that the flies buzzing around the boxes actually deposited eggs on and around the flesh contained in the boxes. This observation made him wonder if these flies were not actually the parents of the maggots which appeared later.

Francesco Redi undertook to test the hypothesis that the blowflies produced in decaying flesh were the offspring of blowflies which laid eggs on the flesh. His experiments consisted of placing fresh meat in a number of jars, some of which were left uncovered and some of which were sealed with thin paper. Flies of various descriptions were soon seen around all of the jars. The flies could not reach the meat in those jars covered with paper, and no maggots appeared in them. On the other hand, the flesh in the open containers was readily accessible to the flies, and hundreds of maggots were soon present. Redi's experiments clearly showed that the dead flesh did not give rise to fly maggots by spontaneous generation. The parents of the flies were previous flies.

Here was one of the first experiments in biology which was scientific in the modern sense. The sequence: observations → hypothesis → controlled experiment → interpretation, was followed exactly, and significant results were obtained.

In his published report on his findings, Redi opened his paper with the following statement:

> Although content to be corrected by anyone wiser than myself, if I should make erroneous statements, I shall express my belief that the Earth, after having brought forth the first plants and animals at the beginning by order of the Supreme and Omnipotent Creator, has never since produced any kinds of plants or animals, either perfect or imperfect; and everything which we know in past or present times that she has produced, came

solely from the true seeds of the plants and animals themselves, which thus, through means of their own, preserve their species.*

Redi's conclusions and the clarity of his experimental results shook the faith of many naturalists in the concept of spontaneous generation. Others disagreed with Redi's interpretation and insisted that spontaneous generation was a sound and true doctrine. And the fat was in the fire. Other biologists started running experiments to test the doctrine of spontaneous generation. Because the importance and methods of controlled experiments were not yet generally understood, many conflicting results were reported. Those naturalists using the refinement of controlled observation were able to extend the conclusions of Redi to many other forms of animal life. Thus, between Redi's publication in 1668 and the middle of the next century, it was shown that gall insects are not generated by plant galls, that toads are not created by mud, that fleas do not arise spontaneously from filth, and so on.

By mid eighteenth century it was fairly well established that living organisms come only from pre-existing organisms, at least in the case of worms, insects, and other visible forms of life. The principle that life comes only from pre-existing life is now known as the principle of *biogenesis.*

But the advocates of spontaneous generation were not yet defeated. They retreated from instance to instance as the concept of biogenesis was advanced by adequate experimental methods. The microscope had been invented in the seventeenth century. The enthusiastic use of this instrument had opened new biological vistas to the eyes and wondering mind of man. The adherents of spontane-

* From a scientific paper written in 1668 by Francesco Redi, translated by Max Bigelow. Copyright 1909 by Open Court Publishing Co.

ous generation retreated into the new and tremendously important realm of the microscope. From this haven they held forth, proclaiming that although biogenesis might be true for the larger organisms, it was not true for the very small ones – moulds, yeasts, bacteria, and protozoa. These 'special' forms of life were held to be generated spontaneously.

The history of science has shown, again and again, that as adherents of a general concept have to retreat to a position of pleading special cases, defeat is imminent. Thus it was with spontaneous generation. It was not yet known that mould and bacterial spores are blown about in the air. Experimental demonstration that these lowly organisms are produced only by others of their own kind was, therefore, very difficult. The spontaneous generation camp further complicated the situation. They asserted that heat sterilization of air, water, and other substances not only kills existing organisms, but also destroys the capacity to produce and support life. This is, of course, a possible interpretation of a sterilizing procedure, even under controlled conditions. Therefore, it had to be shown that the sterilizing effect of heat is to destroy existing life but not the capacity to support living organisms. The complexity of the situation was by no means decreased by the experimental incompetency of some of the men taking part in the controversy. For another century spontaneous generation was to hold out against biogenesis.

The work of Theodor Schwann early in the nineteenth century dealt spontaneous generation a heavy blow when he demonstrated that air which had been heat-sterilized could support life. Louis Pasteur administered the *coup de grâce* in 1862 when he was able to show that poor experimental technique was responsible for all of the evidence supporting the doctrine of spontaneous genera-

tion. The great controversy was over after 200 years (1668 to 1862). The age-old idea that living things can be created spontaneously from non-living substances lay dying in the dust. Biogenesis had carried the day.

But the concept of spontaneous generation lingers on. Many people of today believe that a horse hair will turn into a snake if it is put into water. Such people are a century behind in their education and thinking. Fortunately, none of them is a biologist. Biogenesis – the principle that all life comes only from pre-existing life – is a cornerstone in modern biology. On it rests our principal concepts in genetics, comparative anatomy, evolution, and taxonomy.

So far has scientific opinion swung toward biogenesis, that to speak seriously of spontaneous generation is to commit biological heresy. Heresy notwithstanding, we must postulate that somewhere and at some time an organism appeared where there was no organism previously. However we may define the word organism, the ghost of spontaneous generation still walks. At the level of our present knowledge, we know that spontaneous generation, as the term was conceived and used, is without factual foundation.

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There are several points about the biogenesis controversy that are of significance to us in our exploration of science. Once again we saw something of the great importance of the controlled experiment. The point has already been discussed in detail, and there seems little reason for belabouring it.

Another point of interest is that scientific advances are products of the times. A new theory can become established only when general advances in knowledge and

technical know-how make it possible to test it adequately. The world of science has to be ready for a new concept before a revolutionary theory can appear and survive. The germ theory of disease could not have had any meaning before the invention of the microscope and the acceptance of biogenesis. Darwin's theory of evolution by natural selection would have had little significance had not the idea of evolution been already firmly established in biology. Indeed, the theory probably would not have come into existence at all. Einstein's theory of relativity would never have been formulated if it were not that physical science had advanced to a point where the old physical concepts were no longer completely adequate. Example after example might be mentioned to show that scientific advances are not isolated events, but are the results of previous advances in knowledge and technique.

Another item of understanding to be gleaned from the biogenesis story is that no one man established biogenesis. What Redi started in 1668, Pasteur finished in 1862. Between start and finish many other workers were also contributing to the ultimate solution of the problem. Scientific advances come from the work of many scientists. Occasionally one man will propose a new concept that is soon adopted. But his new theory will have arisen as an untested hypothesis, and will be tested experimentally by instruments and methods coming, in large part, from the accumulated work of others. If his new theory is adopted, it will be by experimental agreement obtained by many workers over a period of time. His may be a timely flash of genius, but the resulting addition to the body of science will be the result of the labours and thoughts of many.

Most new ideas that are proposed are not accepted by scientists in general. In scientific literature there are many such short-lived ideas. To be accepted and established, a

theory has to bring together into one scheme more facts, or has to account for the well-known facts in a simpler, more logical manner than did any previous idea. Scientists do not meet and pass scientific legislation as to what ideas are to be accepted or rejected. Instead, theories stand or fall on whether or not other scientists use them. Once a new idea is published in a scientific journal, other scientists will test it critically. If the new idea is then used by others as a basis for interpreting further work, it may be said that it has been accepted. If the new idea is not so used, it has been rejected. Thus science grows and advances.

By what right do we say that all life comes from previous life? To be sure, it is possible to experiment with a few individuals of a number of species, but billions of individuals of over a million species are in existence. How about all of them? Naturally, it is quite impossible to repeat every biological experiment on every specimen in existence. We simply assume that it is quite unnecessary. The principle of biogenesis has been found to hold good for every organism tested, and we have no reason for suspecting that it might not be equally valid for every species and individual which exists on earth. As a matter of fact, biogenesis is so universally accepted that biologists no longer find it a worth-while subject for research. And that brings us to another assumption that is characteristic of science – the assumption that *nature is unified.*

Without this simple faith in the existence of only one set of natural laws, a single plan for the universe, science as we know it could not exist. The fundamental belief in a unified nature is a very useful assumption. Although I know nothing directly of the nutritional requirements of a gaudy parrot living deep in the jungles of the upper Amazon valley, I would be willing to wager my last dollar

that it requires the same vitamins as does the chicken that laid my breakfast egg. To be sure, we know that different kinds of plants and animals differ in their anatomy, behaviour, and physiology. But as we learn more and more about them, we find more and more evidence of a thread of unity that is fundamental and runs through all the forms of life. Much more of this will be discussed in later chapters.

The influence of the scientist's belief that all of nature is unified goes far beyond these few examples, however. This assumption gives us the extremely important freedom to apply the knowledge of one branch of science to the problems encountered in another. We assume that what we know of physics and chemistry has applications in biology. In Chapter 2 we explored experiments on how bats fly successfully in the dark. In those experiments we made use of knowledge of the physics of sound in order to interpret our biological experiments. When we speak of the processes by which plants use sunlight to manufacture sugar, starch, cellulose, and a myriad of other substances, we are relying on the knowledge of biochemistry. If a chemist takes a plant apart and makes it manufacture sugar in a test tube, we assume that the same chemical reactions were going on in the plant before he ground it up. We assume that not only were those same chemical reactions going on in that particular plant, but also that the same chemical processes are going on in several million other plants, as well.

We look on the universe as one big entity, organized and maintained by one set of rules. With this faith, it is considered that what is known in any one branch of natural science is important and influential in all of natural science. The ultimate goal in science is to fit everything, every phenomenon into one over-all concept. The

arrogance of the goal notwithstanding, it is the basis for believing that separate events may be closely related in principle. It is on this basis that scientific knowledge can be systematized and organized. The assumption is that if we knew all there is to be known about either an atom or a living cell, we would know all there is to know of the universe.

Science is different from other kinds of knowledge in respect to this assumption of a unity. A person who is a skilled musician and composer would find his knowledge of little value were he to undertake sculpturing a statue. In contrast, a knowledge of chemistry is valuable to a biologist, for the various branches of natural sciences are closely related. As modern science has developed, from the standpoint of the type of problems investigated and the sort of understanding sought, physics is the most fundamental and the most advanced branch of science. Natural science can be divided, roughly, into three principal branches – physics, chemistry, and biology. Of the three, physics is the simplest and biology the most complex. That is *not* to say that physics is necessarily easy to grasp; indeed, some phases are quite difficult. By simple is meant the directness of experimentation which is possible.

Every scientific principle or theory is an expression of how groups of natural happenings are thought to be related to each other. The principle of biogenesis is an example of a scientific concept which was adopted only after a long struggle. Two hundred years of controversy were stirred up by the idea that living organisms are created only by similar living organisms. The controversy was caused mainly by the fact that the theory came long before its time. Biology had not advanced in technique and thought to a point where it was ready for a concept

of life that was as sweeping and fundamental as biogenesis. It was accepted for the reason that the amount of experimental evidence supporting it grew to be so overwhelming that opposition was finally crushed. Some theories are accepted much more readily and with much less supporting evidence. Theories for which science is ready are quickly accepted. A good example is Charles Darwin's theory of evolution by natural selection.

The idea of evolution was not new in Darwin's time. Since the time of Aristotle, numerous naturalists had thought it likely that living things had undergone some kind of gradual and systematic change. By evolution is meant a change or development through many generations. Evolution is usually assumed to be from simple toward more complex organisms. As man began to study the structure of the earth and the creatures living on it, he found a great deal of evidence that earthly conditions have undergone changes. It became increasingly apparent that the earth as it has been known during man's sojourn upon it is, in many ways, quite different from what it was millions of years ago. Geologists have tried to read the history of the planet in the composition and arrangement of the layers of rock making up the earth's crust. They long ago found that much of what is now dry land was once ocean bottom. The remains of tropical-type plants and animals were found in cold areas, indicating great changes in the earth's climate. Fossils found in rock strata also have shown quite clearly that plants and animals have differed tremendously during different periods of geologic history. Even without going into detail concerning the fossils found, it is easily understood that the fact of existence of remains of creatures unlike any known in the modern world is good evidence that changes have occurred.

During the eighteenth century a popular explanation for finding fossils of extinct animals was what is known as the 'catastrophic theory'. This idea was that occasionally during the eons of past history, the biological world was completely destroyed by a terrific cataclysm, such as flood, drought, earthquake, or fire. Following such a catastrophe, a whole new set of plants and animals would be created. Thus, instead of any sort of gradual change, or evolution, there was a series of special creations alternating with world-wide catastrophes. The catastrophic theory is not a theory of evolution; it is a theory which attempts to account for geological facts in a distinctly non-evolutionary way. It does not, however, account for very many facts, and, what is more important, it cannot be tested. The only way it could be verified would be for such a catastrophe to occur, with man as a witness and, alas, a victim. The theory contained the seeds of its own destruction, and did not long survive.

Studies of fossils showed that it was possible to arrange these extinct animal forms into series in which the oldest were unlike modern forms and the more recent were increasingly similar to existing species. This sort of evidence indicated gradual – or evolutionary – changes. Other evidence from studies of embryonic development and anatomy, also suggested that a gradual biological evolution had been occurring during the earth's long history. By the early part of the nineteenth century, biology had developed to the point where it was ready to accept and use a theory of evolution. What was needed, however, was an acceptable idea on how such an evolution could have occurred.

In 1809 the Chevalier de Lamarck, a French biologist, published a book in which he set forth a theory of how evolution operates. In Lamarck's theory, evolutionary

changes in a species were caused by the habits and physical development acquired by individual animals. This theory is called 'evolution by the inheritance of acquired characteristics'. Such a theory gives a plausible explanation for many of the observed facts concerning evolution. By the Lamarck theory, the giraffe has evolved an extremely long neck because it has always stretched its neck, trying to eat leaves high in trees. Imagine a giraffe-like animal with a short neck. In feeding on the leaves of trees, it can reach only the lower ones. But after it strips off all the low leaves, it tries to reach the higher ones. This results in constant stretching, so that as the giraffe grows older, its neck actually becomes longer. This longer neck, which has been acquired by muscular effort, is transmitted to the giraffe's offspring. The little giraffes will start off in life with longer necks because of the use to which their parents had put their necks. Thus, after many generations of continual neck-stretching, the giraffe as we know it was evolved. According to this theory, the children of a race-horse jockey will be better horsemen than they would have been had their father (same man) happened to be a book-keeper. In short, Lamarck's theory says that characteristics (habits, skills, physical development) that are acquired by an individual will be passed on to his offspring.

Lamarck's theory became very popular among scientists because the idea that acquired characteristics may be inherited had been around a long time. And Lamarck's theory was the first coherent 'explanation' of evolution. Lamarck had simply taken an already firmly entrenched idea and had applied it to a specific biological problem – evolution. As will be explained later, Lamarck's theory no longer finds a place in modern biology. At the time Charles Darwin received his biological training, however,

the Lamarck theory of evolution was generally accepted and taught in schools.

Darwin was a patient and thorough observer, and over many years he was intrigued by the amount of variation to be found among individuals of the same species of plant or animal. As a young naturalist, he had made good use of an opportunity to travel about the world. As the naturalist aboard H.M.S. *Beagle*, he had broadened his biological experience immensely during a five-year cruise. In the great variety of plants and animals that he studied and observed, he became interested in the small noticeable differences between individual specimens. The differences which impressed him most were trivial differences of the sort that we all see every day and dismiss as unimportant. These are the differences that make one horse win a race and others lose it, and unless we had a bet on the race, such a difference seems of no consequence. Small individual traits mark the difference between winner and loser in agricultural shows, sports meetings, flower shows, dog shows, and beauty contests. One set of observed facts that was to contribute to Darwin's theory was that many small individual variations occur in any population of plants or animals.

Another idea that influenced Darwin's thinking came from an essay. In 1798 Thomas Malthus published an article in which he pointed out that human populations tend to increase in numbers until they outgrow their food supply. Malthus used this argument to support the idea that in any well-populated country most of the people will be poorly fed and clothed and generally poverty-stricken. He claimed that this deplorable situation was normal and inescapable because, were a more prosperous situation brought about, the population would simply increase until, once again, there would not be enough for

all. Conditions of poverty tend to increase death rates and prevent the population from getting too large. Thus, according to Malthus, a human population must reach an equilibrium at a low subsistence level. Of course, we like to think that in our modern society this Malthusian effect need not come into play as long as our technology continues to advance. Charles Darwin saw that what Malthus said of human populations should also be true of any population of plants or animals. Since the days of Malthus and Darwin, experiments with animal populations have demonstrated the validity of this interpretation.

Considering the rate at which even comparatively slow-breeding animals reproduce themselves, it appeared obvious to Darwin that most offspring must fail to survive to maturity. An example of the potential population brought about by even a modest reproductive rate would be a species of bird in which each couple hatches only two eggs per year, during a reproductive life of six years. If a person started with a single pair of these birds, he would have a flock of about 4,000 birds in twelve years – two full life-spans – later. Only rarely does a species have an opportunity to display the amazing power of its ability to reproduce. Chance entry into a new territory sometimes results in such a display. The introduction of the rabbit into Australia is a classic example, for that continent soon became literally swarming with rabbits. Insect outbreaks are also common examples. Under normal conditions explosive increases do not occur, but the number of a species tends to remain about the same, or to increase or decrease slowly.

If only a few can survive, what determines which survive and which fail? Darwin reasoned that those best fitted for their way of life would have the best chance of making

the grade. In a group of essentially similar animals, how can some be better fitted than others? It must be in some of the individual variations, the little differences that make each organism an individual. Any small characteristic which made its owner a bit more efficient at day-to-day living should give that individual a better-than-average chance to reach maturity and to beget offspring. The efficient variation might be passed on to the offspring, which would then also have a better than average chance for survival. Thus, the direction of evolution might be determined simply by a constant natural selection of only the individuals best fitted for survival and reproduction. This is the essence of Darwin's theory of evolution by natural selection.

Darwin's theory would explain the evolution of the giraffe's long neck on a basis which is quite different from that by which Lamarck's theory explained it. As we saw earlier, the Lamarckian idea was that the modern giraffe has a long neck because of the efforts of its ancestors to reach higher and higher. These efforts resulted in longer necks, which were passed on to subsequent generations. Darwin's theory says that more ancestral giraffes were born than could survive to maturity. Some giraffes just happened to have slightly longer necks than others. In competing with each other for a limited food supply, those with the longer necks were able to reach higher in the trees and feed on leaves unavailable to their short-necked neighbours. Thus they had a better than average chance of surviving and reproducing. Their offspring tended to inherit the longer neck. Of the offspring, those that had even longer necks would have the best chance.

Darwin's theory of evolution by natural selection provided a powerful unifying principle in that it brought all the evolutionary changes observed in nature into one

inclusive scheme. There was no longer a need to look for separate explanations for the evolution of each plant and animal. It brought it all – plant, animal, and environment – into one plausible theory. It provided an explanation of how the multitude of different kinds of living creatures could have been created from fewer and simpler forms in nature's crucible over hundreds of millions of years on a constantly changing earth.

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Earlier we saw that biogenesis was accepted only after a very impressive mass of experimental evidence was brought out to support it. Darwin's natural selection theory of evolution was accepted much more quickly and with practically no experimental evidence. In fact, as first presented, it was more of a hypothesis than a real theory. Though no experiments had been run, the hypothesis was consistent with an amazing array of simple observations. Biology was fully ready for the concept of natural selection by the time it actually appeared. That the time was ripe is shown by the fact that the theory occurred to another Englishman, Alfred Wallace, at about the same time that it did to Charles Darwin. Wallace was in Malaya, which is about as far as one could be from Darwin's laboratory in England. Wallace and Darwin reached the same conclusions, with neither man knowing of the other's work. They presented their theory jointly before a London scientific society, after discovering the identity of their ideas. Because he had compiled more extensive observations and was more active in championing the theory, Darwin is always given much more credit than is Alfred Wallace.

One of the major reasons for the acceptance of the natural selection theory in spite of its lack of experimental

backing was its close agreement with a great range of observed facts. It was – and still is – difficult to look at a mastiff and a lap poodle, breeds of dogs created by man from a single wild species by the simple tool of selective breeding, and doubt that natural selection has been a factor in evolution. By selection, man can shape a great number of plant varieties and animal breeds tailored to his need. How much more could be accomplished by a ceaseless natural selection over millions of years. Since the time of Darwin, the theory has been explored intensively and, of course, tested experimentally. In some of its aspects it has been strengthened; it has been greatly strengthened by modern genetics. It is now thought that natural selection is by no means the only important mechanism involved in evolution, however. The picture is far more complex than anything envisioned by Charles Darwin.

Setting forth theories without experimental evidence is a dangerous practice. Darwin also formulated two other theories, neither of which has survived. Both failed to pass the test of experiments. One was a theory of inheritance. The theory of natural selection requires that there be some means by which favourable characteristics are passed from parent to offspring. In Darwin's day, nothing was known of genetics, for that branch of biology did not begin its meteoric rise until after 1900. Darwin's fanciful scheme of inheritance was blown all apart, once the first developments in modern genetics came about. Darwin's other theory attempted to explain colour patterns and mating behaviour in birds, and it, too, failed to pass the test of time and experiment. This theory was called the sexual selection theory, and was based on the idea that females select the males with which they mate. Thus there may be an evolution of sexual characteristics such as gaudy plumage and bizarre courtship behaviour in birds. It

might also account for antler size in deer, moose, etc. These characteristics might not be of value to the survival of the bird or mammal. They might have the important effect, however, of increasing the opportunity to mate and to transmit the characteristic to a subsequent generation. Evolution in the male might be in part dependent on the whims of the female. Experiments on animal behaviour have failed to lend any support to Darwin's theory of sexual selection.

In all of this, what became of Lamarck's theory of evolution by the inheritance of acquired characteristics? Lamarck's theory differed from the natural selection theory in some very important ways. Darwin's theory went far beyond that of Lamarck. The idea of natural selection accounted for more observed facts. It explained both evolution and the fact that plant and animal populations normally remain about constant in number. The natural selection theory brought both of these observed effects into one coherent picture. The Lamarckian theory was silent on the population problem, and attempted to explain evolution with regard to individual or species survival. Darwin's theory was also consistent with what animal breeders had been doing for many years. Different breeds of horses, cows, dogs, sheep, and so on, had been developed by selective breeding; that is, by mating individual animals showing the desired form or colour. Darwin simply said that a comparable selection for fitness goes on constantly in nature. Lamarck's theory of evolution was not based on any such similarity to the breeding of domestic animals. Thus, the theory of evolution by natural selection was a broader, more inclusive scheme than the older idea it replaced.

There is another very important reason why Lamarck's theory has been replaced by the Darwinian theory. That

reason is one of experimental evidence. Genetics, the most exact of the branches of biology, has steadily confirmed the concept of evolution by natural selection. Studies of plant and animal population dynamics have also supported the theory. Lamarck's theory has been discarded because there has never been the slightest shred of experimental evidence to support it. Many attempts have been made to test the idea of inheritance of acquired characteristics, but the theory has failed every test. No theory can last long if it cannot be confirmed by experiment, for without experimental support it cannot be part of science.

In spite of these discrepancies, however, Lamarck's theory is the 'official' genetic theory in Communist countries. There it is known as Michurinian genetics, being named in honour of the Russian, Michurin, rather than the Frenchman Lamarck. For a number of years Russian biologists were not allowed to report the results of genetic studies which were inconsistent with the idea of inheritance of acquired characteristics. For purely practical reasons, the official attitude has been enforced less vigorously during the last few years. But the genetics of Michurin is still the only Communist-sanctioned theory of inheritance. This is simply because the doctrine is more consistent with Communist beliefs than is modern genetics. Truth by proclamation. It has been done before. William Harvey demonstrated in 1628 that blood circulates through the body; this idea was so revolutionary and contrary to firmly held beliefs that the major scientific society of France passed a resolution to the effect that blood does not circulate. But it went on circulating anyway.

There are many theories in science, theories that are meaningful and illuminating. Theories are of great scientific importance because they are attempts to fit many facts

into one meaningful picture, like fitting the pieces of a jigsaw puzzle together to form a picture. Theories give us a means of forming workable concepts and an ever-improving understanding of the world in which we live. If a theory stands the test of experiments of many sorts and over a long period of time, it becomes established as a principle or law. Biogenesis is known as a biological law. Natural selection has become a principle. In physics, many laws are known – conservation of matter and energy, gas law, laws of motion, and so on. Occasionally new findings will completely destroy an old law; so even our best-established ideas may not be the last words to be said on a subject.

4

FROM FACT TO FINISH

Pilate said to him, 'What is truth?'
John 18:38

IT is mere weakness to pose the question 'What is truth?' only to wash one's hands of the whole problem, as was done by a Roman in Jerusalem nearly 2,000 years ago. However elusive, truth is always the goal of an honest and inquiring mind. The ideas we hold, the scientific theories we accept, are not in themselves truth, but are man-made approximations of it. A 'scientific truth' is not an absolute truth, but only a currently acceptable theory. Indeed, the very term 'scientific truth' is not part of a scientist's working vocabulary. A theory is nothing more nor less than an idea that brings a large number of observations into one scheme.

As was stressed in the discussion of experiments and how theories grow, the only 'facts' involved in science are observations of things and events. Since we cannot work with what we cannot observe, we have to assume that what we do observe is hard, incontestable fact. If each such fact were an isolated event, unrelated to all others, our world would be chaotic and science would be without meaning. So we assume that the things and events observed can, in some way, be related one to another to form an organized pattern. A theory, then, is a description of our very best idea as to how such facts fit together.

It would be indeed strange if natural facts were such that only one interpretation could be fitted to them. On

what basis do we formulate a theory? By what reason do we think that a theory has any validity, even though it appears to 'agree' with observed facts? These questions bring us to the subject of the reasoning processes involved in forming a hypothesis, interpreting an experiment, and arriving at a theory. This is a subject of great importance to an understanding of science, and volumes could be, and have been, written on scientific logic and reasoning.

Science must start with observed facts; the more at hand the better, but some we must have. From these facts, we try to draw a picture which is consistent with all of them. This sort of reasoning is called *inductive reasoning*. Induction is simply a matter of drawing conclusions from a set of observations. This is the basic reasoning process used in science. In the examples of experiments on the flight of bats and the growth of plants, we arrived at ideas by considering groups of facts. In the formation of the principle of biogenesis and the natural selection theory, reasoning was also inductive. Induction is taking sets of observations as facts and then bringing these facts together into a single picture.

Induction is not the only way to reason, however. It is possible to reverse the reasoning process. Reasoning in this reversed sort of way is called deduction. *Deductive reasoning* involves accepting a general idea to be fact, and then judging individual cases accordingly.

A simple example should make clear the difference between inductive and deductive reasoning. Suppose that someone asks, 'What kind of blood cells do eagles have?' The question can be answered in either of two ways. The inductive approach to the problem would be to go out and catch a few eagles. Examining some samples of eagle blood under a microscope would provide an answer to the question. Under the microscope we would see the

blood cells of an eagle; these would be undoubted facts. From the type of blood cells we found, we would conclude that we had learned something about the blood of eagles in general.

Since catching eagles is a tricky business at best, the easiest way to answer the question would be to try to find something about it in a book. A book about birds will tell us that all birds have nucleated red blood cells. We would then reason that since the eagle is a bird, it too must have nucleated red blood cells. The question would have been answered without our having to go out chasing eagles. This way of answering would be deductive. In this line of reasoning, the general statement 'All birds have nucleated red blood cells' is taken as being fact. The particular question about eagle blood is deduced as a simple instance.

During the medieval centuries there was little inductive reasoning, and most of what was known about nature was by deduction. A story is told about two scholastic monks and a student. Perhaps it is a true story. One cold winter evening the three of them were sitting before a cheerful fire discussing matters academic. At one point in the conversation, the student asked, 'How many teeth has a horse?' Neither of the monks knew offhand. So, they got the works of Aristotle from the shelf and started looking for the answer. The word of Aristotle was considered unquestionable in those dark days. For two hours they searched, but they found no clue concerning the dental furniture of horses. Finally the student naïvely suggested that they all go to a neighbouring farmyard and look into a horse's mouth. This so shocked the sensibilities of the two monks that they threw the poor student out of a window and into the snow. And they turned back to their books.

Deductive reasoning has a place in science, and it very

frequently plays an important role. Mathematics is a purely deductive system; certain things are assumed to be true, and from them the rest of the system is deduced. These assumptions are called postulates and are considered self-evident. They form the foundation of the mathematics. Mathematics is not a science, but is a separate body of knowledge in its own right. In conjunction with scientific work and as a language for science, mathematics has proved to be a tremendously useful tool. It must, however, always be used as a deductive tool, and the results of a mathematical analysis of a problem can have no real scientific standing until they are supported by factual observations.

The classical geometry of Euclid is a system of mathematics that was built up from a small number of assumed truths, or postulates. One of these postulates is that the shortest distance between two points is a straight line. From a common-sense standpoint, it seems quite certain that the shortest route from one place to another is a straight path, a 'beeline' as it were. It cannot be proved, however, and must be taken as a self-evident truth. Isaac Newton, one of the founders of physics, used this classical geometry as the language for the expression of his famous laws of the physical universe.

A number of mathematicians have invented mathematical systems based on postulates differing from those of Euclid. In the middle of the nineteenth century a Georg Riemann devised a complete and logical system which included the unlikely assumption that an arc is the shortest distance between two points. Riemann's geometry was interesting as a sort of mathematical toy, but it was thought to be useless in science, because its starting postulates were considered untrue. By the end of the nineteenth century, physical science had advanced to a point where

the classical physical theories were no longer completely adequate. Physicists were faced with a number of observed facts that could not be accounted for by Newton's laws. In 1905 Albert Einstein brought forth a solution to the dilemma. Einstein's solution was his relativity theory. The mathematics of the theory were based on the system of Georg Riemann. And so we now think of space itself as being curved.

Scientific concepts are obtained inductively, simply by forming theories and laws from sets of related observations. But deduction also plays a part in the scientific method, for a hypothesis is very apt to be a deduction which is about to be tested. Then, too, the applications of accepted theories and laws are usually in the form of deductive predictions. Although the situation is quite complex, science is essentially inductive knowledge, by virtue of the requirement that all ideas and deductions be tested experimentally.

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Observations and experiments may be interpreted in different ways, some simple and some very complex. The conclusions we reach must, of course, be consistent with the facts at hand. They should also be as direct and simple as we can possibly make them. It is never to be supposed that nature is unnecessarily complicated. Whenever there is a choice, we follow the rule that the simplest theory is probably the most nearly correct one. This rule of simplicity is really an assumption that cannot be proved. Perhaps nature is always extremely complicated, but it does not seem likely. As a matter of common sense, why propose an involved, complicated scheme when a simpler one will explain the facts just as well? To do otherwise would be about as sensible as travelling eastward around the

world to reach your neighbour's house which is next door to the west. The rule of keeping ideas simple is sometimes known as 'Occam's Razor', after its originator, William of Occam, a fourteenth-century philosopher. It is indeed a razor, for with it we can cut away the trimmings and the unneeded, and keep our scientific ideas precise and objective. But, as we shall later see, this razor can be a dangerous weapon, and unless we are very careful, we may use it to cut our own throats.

The classical example of an over-complicated scheme being replaced by a simpler one is that involving the ideas that have been held concerning the solar system. In ancient times it was thought that the earth was at the centre of the universe. The sun, moon, planets, and stars rotated around the earth. The earth was thought to be flat and more or less like an island. The stars were lights hanging from huge spheres which rotated around the immovable earth. The idea of the earth being the centre of the universe is natural, since every day we see the sun rise in the east, climb across the sky, and sink in the west. Such an earth-centred universe is also quite consistent with the human sense of self-importance.

The earth-centred idea of the universe became very complicated when attempts were made to calculate and to draw the orbits of the planets and to predict their positions at any particular time. These difficulties were solved, however, and Ptolemy, a Greek astronomer of about the second century, devised a scheme describing the orbits of moon, sun, and the known planets around the earth. The moon and the sun were described as travelling in circular orbits. But the planets had to move in complex orbits. The planetary orbits might best be described as being like a coil-spring stretched around the earth. Although the orbit was circular, the planets described a spiral motion

around the central path. The calculations involved in formulating and using the Ptolemaic scheme were extremely complex, and the accuracy with which it was used is quite surprising.

After the passing of the Dark Ages, the discovery of the New World and circumnavigation of the earth did much to broaden the horizons of human thought. With acceptance of the fact that the earth is spherical like the planets, the way was paved for a new concept of the universe. In 1543, Nicolaus Copernicus advanced the idea that the sun is the centre of the solar system. The earth was considered to be rotating around the sun, as one of the sun's planets. The spiral pathways of the planets were replaced with simple circular orbits. The apparent movement of the stars was accounted for in simpler and more direct terms than had been possible with the old Ptolemaic system.

The Copernican scheme of the solar system was much more elegant and simple than the older concept. Many objections were raised to the new idea, however. Some of the objections came from the quarters of organized religion, in that the new idea of the earth travelling around the sun was held to be contrary to Holy Scripture. Other objections involved such questions as 'If the earth is spinning, why are we not flung off?' These controversies need not be detailed here, because we are concerned with the structure of science, not its history. But they tell us an important story, for here was an idea that was contrary to accepted belief and common sense. In everyone's experience the sun goes around the earth, as do the stars and the moon. And it seems only common sense to think that the earth is both flat and standing still, for if it were moving, there should be a feeling of motion.

Astronomers adopted the idea of a sun-centred solar system because it simplified their work. Then too, it was a

much more logical and elegant system than could be made from the earth-centred system of old. So the Copernican concept was eventually adopted, and the Ptolemaic solar system passed out of style. All of this change – round earth, sun-centred planets – occurred well over a century before the dawn of modern science. It is probably the oldest example of an idea which was adopted only on the basis of its being simpler than the theory it replaced.

Today, in the mid twentieth century, there are people who do not believe that the earth is either round or in motion. There is, for instance a group that maintains that the earth is flat, like a gramophone record, with the north pole in the centre. To them, going 'around the world' is a voyage in which a circle is described on the flat disk. The edges of the earth are made up of huge mountains of ice known as the antarctic. Such people must find it difficult to account for great-circle sailing and geographical trifles such as the south pole.

The simplest idea is considered best because it gives the impression of going directly to the heart of the problem. There is, however, more to the matter of arriving at an acceptable theory than just agreement with observations and simplicity. In the first place, it would be very unusual if a major theory were in agreement with each and every bit of information on the subject. Because of inadequate methods, or incomplete knowledge, observations may not always be accurate or properly expressed. Theories are by no means perfect, and may require changes. Or they may even have to be scrapped entirely, as we learn more.

The matter of simplicity is, itself, not exactly simple. What constitutes the simplest explanation of a set of scientific results? The simplest should be the most direct and understandable. To most people, the simplest and most understandable picture of the solar system is the

earth-centred idea of antiquity. To the astronomer and the astrophysicist, a sun-centred system is simpler, because it can be handled more easily from a mathematical standpoint. It also has the advantage of allowing more efficient deductive use. The sort of simplicity which is desirable in a theory is largely a matter of its usefulness as a working concept, as a tool for further work. It is not a matter of how easily it is visualized or understood in every-day terms.

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Theories which involve ideas which seem logically necessary from the standpoint of common sense are very appealing. They can, however, be somewhat dangerous from a scientific point of view. A case in point is the 'ether theory' which was developed and accepted in the physics of the eighteenth and nineteenth centuries. There was no direct experimental evidence in support of it, but it appeared to be logically necessary. It had to be thrown out – lock, stock, and barrel – in the twentieth century. Let us look, briefly, at this ether theory.

Some physical forces have the form of waves. Sound, for instance, is in the form of waves in the air. The frequency, amplitude, and speed of these waves can easily be measured. The wave itself is simply a disturbance that spreads from molecule to molecule. The waves spread out from the source and are carried by the air. If a noisemaker, such as a bell, is set up in a vacuum, it produces no sound. There is no sound because within a vacuum there are no air molecules to be disturbed. A wave must have some sort of a medium to carry it. Light also has the properties of waves, and so do electromagnetic forces. But if a light or a magnet is put in a vacuum, it still works. If light and magnetic waves do not require air as a carrier, there must

be some other carrier present. Since that carrier is present even in a vacuum, it must be different from ordinary molecules, and might even be a property of space itself. This strange stuff that could not be separated from space was called *ether*.

The concept of ether as the stuff of space was adopted as a logical necessity and a simple way to explain some of the properties of light and magnetism. As physics advanced and more and more observations needed explanation, the ether theory became increasingly complicated and unwieldy. All sorts of different physical properties had to be assumed to be characteristic of the tenuous stuff called ether. If all of space is filled with ether, the earth must be moving through it. It should be possible, then, to demonstrate the existence of the ether by measuring its effect on the speed of light. It should have a slowing down or drag effect on beams of light pointed at right angles to the earth's motion. Very precise and elaborate experiments were carried out to check this point. No such drag effect was found. This was hard to explain. The theory of relativity subsequently showed that the speed of light is not affected by the motion of the earth or any other object. Thus the presence of ether could not be demonstrated, nor could its effects be measured. From a scientific standpoint, this made the ether theory meaningless. And so the theory was discarded. What had once seemed to be a simplifying idea and a logical necessity had become an encumbering article of excess baggage.

In trying to decide what makes one theory acceptable and another unacceptable, a person is forced to make some value judgements. In the first place, it is quite obvious that not all observations are going to be of equal importance to the subject at hand. The scientist is then required to decide which facts are the most pertinent.

Such a decision is a value judgement, and is likely to be a personal opinion, unless the matter can be decided experimentally. Being but a man, a scientist is not able to be completely impartial in his interpretations. As an individual and as a member of a community, he will hold certain philosophical, religious, and political beliefs. A scientific theory which he feels is somehow inconsistent with those beliefs he will oppose. It is very easy for a person to change his ideas on a subject that is not important to him personally. But it is much more difficult when prior commitments of thought, effort, or ideology have been made. This sort of difficulty was the cause of some of the opposition to Darwin's theory on evolution. This type of opposition, or even support, has nothing to do with the scientific merits of a theory, but results from the impact of a theory on personal beliefs. Nevertheless, such personal factors play a role in the interpretations we make of any set of observations, however scientific we may try to be.

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A scientific theory should not close the door to further research on a subject. No theory is ever to be considered the last and irrefutable word, and no theory should remove the problem to an untestable realm. One of the oldest problems in biology is the origin of life on earth. A number of ideas have been suggested, and one theory is that life came to this planet by being transported on a meteor from somewhere else. It has been labelled 'the germ theory of life' and says that primitive forms of life, such as bacteria, may have originally reached the earth from outer space. Their arrival here started the whole process of organic evolution. This odd idea actually cannot be called a theory since there is no evidence in support

of it. It is a hypothesis. It is not only a hypothesis that cannot be tested experimentally but also shows the weird characteristic of moving the whole problem to another planet. Since it has been neither testable nor useful, it has found no place in science.

The notion that life came to earth from outer space is not an impossible idea – it may have happened. It has not been a scientifically useful hypothesis because no one has been able to test it. With the development of rockets and man-made moons, space travel is certainly within the foreseeable future. This means that it will be possible to determine whether life exists on other planets and whether any bits of living matter are to be found in space. To a limited degree, the 'germ theory of life' will become a testable hypothesis. It will be testable to only a limited degree for two reasons. First, suppose that no life is found drifting about in space. That will not prove that it could not have happened; it will show only that it would be an uncommon occurrence. Second, suppose that 'germs' are occasionally encountered out there in space. Such a finding would not mean that life could not have arisen independently here on earth. So the issue would not be decisively settled either way. The germ theory of life would still be scientifically unsatisfactory, and would have to wait for a bright young space-biologist of the future to devise a better way to test it. Few scientists believe that the earth could possibly be the only life-bearing planet in the whole vast universe. Living things are almost certain to have arisen elsewhere, on other planets in other solar systems.

Spaceships and satellites will show that man has finally defeated gravity, that relentless force which keeps our feet on the ground and wears our bodies out. Another of the characteristics of scientific theories is illustrated in the

ideas that have been held concerning gravity. Four hundred years ago, the fall of a stone to earth was explained on a basis that would now be considered somewhat idiotic. It was believed that everything seeks its natural resting place assigned to it from the beginning of time. A stone in the air is out of place; its place is on the earth. The stone, therefore, seeks to return to its proper station in the scheme of things, and it returns to the earth as quickly as possible. Smoke, on the other hand, was assigned a natural position in the sky. Instead of falling to earth, smoke rises, because it, too, seeks its natural resting place. This way of explaining natural occurrences such as objects falling, seems naïve to us today. It is an unscientific idea for two obvious reasons. In the first place, it does not allow for experimentation. How can we run experiments to find out more about 'natural resting places'? It is a dogmatic assertion which closes the door to any extension of knowledge. The second defect in the ancient idea is that it is anthropomorphic. A rock seeks its natural resting place? How do we know what a rock seeks? To say that an object seeks a particular condition is the same as saying that it strives toward a goal. From personal experience we have a concept of seeking and striving; but it is only subjective. That is, experience of seeking and striving comes only from within ourselves. To say anything or any animal seeks or strives is to give it human characteristics. To project our experiences into other objects is anthropomorphism. We must not put our own personalities into other things as observable characteristics, because such thinking involves assumptions that cannot be tested. Besides being untestable, anthropomorphism is an unnecessary complication. Thus it violates the rule of keeping our theories as simple as possible.

After the work of Isaac Newton in the seventeenth cen-

tury, the falling of a stone to earth was given a more sophisticated explanation. Formally stated, Newton's law of universal gravitation is: Every particle of matter in the universe attracts every other particle with a force that varies directly as the product of their masses and inversely as the square of the distance between them. In short, the bigger two objects are and the closer together they may be, the stronger is the force of the attraction between them. In the example of the stone falling to earth, the earth is a good-sized chunk of stuff, and it will exert a powerful attraction on anything very close to it. Since the earth is so large, it has a great deal of inertia. A small object such as a stone is drawn to it, rather than the earth moving noticeably to the stone. Newton's law of gravity has proved to be an extremely important and useful concept. The form in which it was stated allows mathematical applications; these forces, masses, and distances can be measured. The whole idea can be tested by experiment. Its consequences can be predicted deductively and then tested inductively. As a scientific law it is neat, simple, and useful. It is interesting to note that the explanation of gravity given in the modern theory of relativity is still more refined in that it does not require the use of the idea of attraction. The relativity theory does not invalidate Newton's law; it simply goes far beyond it.

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In this discussion of ideas and theories, the terms 'agreement' and 'consistent' have been used very frequently. 'A theory must agree with the facts; that is, be consistent with them.' What is actually meant by this? How can we tell whether or not an idea agrees with a group of facts? This is part of the complex problem of how we think, but the simplest way to look at it is from the standpoint of

prediction. Scientifically, an idea agrees with facts if we can use that idea to predict what will occur under particular conditions.

Suppose that we have a perfect spring scale and some perfect one-ounce weights. The only thing we do not know about this scale is what the numbers on the front mean. Do they read in ounces, or pounds, grams, or what? We want to run some experiments and develop a 'theory' as to how the scale is marked. So we start by putting one one-ounce weight on the scale. The pointer moves and comes to rest pointing at the number 1. We think immediately that the scale is marked so that it reads in numbers of ounces. If this idea agrees with how the scale is actually marked, we can predict that if a second one-ounce weight is added, the pointer will move to the number 2. Now we add that second weight, and the pointer moves to 2. Very good. The results we have obtained tend to confirm or support the theory that the scale is marked in numbers of ounces.

When we add the third one-ounce weight, we do so with the expectation that the pointer will indicate 3. But it does not; it comes to rest about half-way between 2 and 3. The idea that the scale is marked in ounces is now in disagreement with the observations we have made. We are no longer able to predict what the scale will read if more weights are added. Let us add another weight and see what happens. Now the pointer is exactly at 3. There are four one-ounce weights on the scale, and the pointer is at the number 3. Obviously the scale is not marked so that it simply counts the number of ounces being weighed. But how is it marked? We need a new idea, one that will agree with our observations and will also enable us to predict accurately what the pointer will read if we add more weights.

Suddenly, an idea comes to mind. Maybe the scale is marked in the terms of a geometric progression such that each number has twice the 'ounce value' of the previous number. Then one weight would cause the pointer to indicate 1. Two ounces would be twice as much weight, and the pointer would read 2. Twice times two ounces is four ounces, and with four ounces on the scale, the pointer should come to the number 3. We now have a new theory, and it agrees with all of our observations. On the basis of our new 'geometric progression theory', we will predict that if eight one-ounce weights are placed on the scale, the pointer will move to the number 4. We try it, and that is what happens. Our theory is consistent with the facts observed – all of them. And it has allowed accurate prediction. It may be a very odd scale, but we can work with it because we have a theoretical understanding of it.

In the case of an actual spring scale, or any other apparatus which does not perform according to expectation, we first suspect that the equipment is not in perfect working order. We do not throw a theory away only because a machine does not operate correctly. We must always assume, however, that nature is in perfect working order. When our theories do not fit our observations, theories must be changed. The rule that nature is never wrong, that phenomena occur just as they are supposed to, may seem obvious. Obvious or not, people sometimes demand that nature conform to their narrow ideas.

A number of years ago, an aeronautical engineer was curious about how bumblebees fly. A bumblebee has rather small wings and a large bulky body. This engineer measured the bee's wings and its body size and weight. He calculated the air resistance, wing surface, and so on. When he was all through with his calculations, he reached the conclusion that the bumblebee is not built correctly

for flight. Aerodynamically, it should not be able to get off the ground. Newspapers built the story up with accounts of how 'science' had proved that bumblebees cannot fly. But the illiterate little bumblebee went on flying. Any scientific study of how bumblebees fly must start with the observed fact that they do fly. If a set of calculations is not in agreement with that fact, the calculations are in error. The field of aerodynamics has doubtlessly advanced to the point where the flight of bumblebees is now theoretically possible.

A scientific theory must be as simple as possible, be capable of experimental testing, and be consistent with all of the pertinent observed facts. These are rigid and relentless requirements. There is no room here for soft thinking and pet philosophies. In the cold objectivity of scientific procedure, some of our most cherished concepts find no place. Any peculiarly human way of looking at life and universe is anthropomorphic; indeed, that is the very definition of anthropomorphism. Any such concept that cannot be measured objectively and made the subject of impartial observation can find no validity in science.

Beauty, tragedy, morality, purpose, value, and immortality are but a few of the concepts not included in the scientific scheme. Because they are so important to human thought and living, one might be seriously disturbed by their absence from science. The scientist's zeal for simple and testable knowledge has led him to trim away the excess fat from the body of science. One may begin to suspect that his enthusiasm for cutting away the fat has resulted in his also hacking off the meat, leaving us only a skeleton. Perhaps when we thoroughly understand the skeleton, we can start studying the meat.

The reduction of knowledge to its simplest and most objective terms is inevitable in the interest of efficiency

and usefulness. Take, for instance, the matter of consciousness. Our only real experience with consciousness is with our own individual personal states of being conscious. In ourselves we think of consciousness as being a state of continual awareness which is in no way dependent on an ability to react overtly. We are perfectly willing to assume that other people are also conscious. This is really only an assumption, for we cannot observe consciousness in anyone but ourselves. For me to assume that you experience an awareness which is basically similar to my own consciousness seems to be a safe assumption. Similarly, a person may be willing to assume that some animals are also conscious – monkeys, dogs, cats, horses. When we assign a state of consciousness to animals we are treading on more dangerous ground. Animal behaviour can be observed and can be experimented with, but behaviour is not necessarily a measure of consciousness. Thus, it is easily seen that to assume an animal to be conscious is to go beyond what can be tested, to add an unnecessary assumption, and to inject an element of anthropomorphism into our theories. Besides all of these reasons, there is a practical question of where to draw the line. If we say a dog is conscious, shall we also say that a lobster is conscious, and so on down to a single bacterium? However real consciousness is to the human individual, it is not a useful concept in science because there are no methods for dealing with it.

The same reasons for calling consciousness an unscientific idea can be applied to the other strictly human ideas of beauty, morality, and so on. Some of these ideas will be taken up again in a later chapter. The unsuitability of the concepts from a scientific point of view does not mean that they are meaningless or unimportant. They cannot be part of science because they cannot be dealt with

scientifically. To deny the validity of an idea requires that it be tested and found wanting. Spontaneous generation and the inheritance of acquired characteristics were both theories whose validity was denied by experiment. These ideas could be tested and could be refuted. In science if a concept cannot be tested, it cannot be refuted, and cannot be supported; it can only be ignored.

5

A CHAIN OF EVENTS

> 'When you can measure what you are speaking about and express it in numbers, you know something about it; and when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind. It may be the beginning of knowledge, but you have scarcely in your thought advanced to the stage of a science.' *Lord Kelvin*

THESE words of Lord Kelvin, a prominent British scientist of the last century, form a tough-minded and dogmatic statement of what sort of understanding is reached through science. The statement is typical of the attitude of nineteenth-century physics, and by and large is still true today. In the twentieth century, however, some doubt has been cast on the neat mechanical world envisaged by the science of that period.

What is really meant by the idea that science is only measurement? Surely anyone can see that there is more to our world than inches, pounds, and other such measurables. The relationship of one thing to another can be more, certainly, than the relation of one set of measurements to another set of measurements. The relationship of a mother to a baby is hardly to be expressed fully in the terms of either measurements or a simple sequence of events. Nevertheless, science is largely limited to such measurements. To understand why this is so, and to understand what is meant by measurement, we must explore the whole idea of what is real.

It will be recalled from an earlier chapter that one of the assumptions on which science is based is that nature – the world in which we live – is understandable. By studying it diligently and honestly, we will eventually understand it. The world of nature will not prove to be so mysterious that it is imponderable and quite beyond human understanding. It was also pointed out in that chapter that one of the ways that we are able to understand the great multitude of phenomena spread before us is to think of one occurrence as being caused by another. This is, of course, the idea of a chain of events, a cause and effect series. In this fifth chapter, we examine these ideas more closely.

Philosophers and other people who pause now and then to ponder some of the riddles of the universe have long realized that each person lives in a world of his own. The centre of that world is his own mind. The sort of world he lives in is determined by his experience, temperament, and intelligence. This is a subjective world, a private kind of thing. How it corresponds to a real objective universe that is independent of any human mind is a major problem in both philosophy and science.

The things and events which occur in the external world act on our sense organs (eyes, ears, etc.), and the mind which receives these sensory signals weaves them into the fabric of a perceived or experienced reality. Since we cannot get out of our own minds, our senses provide our only contact with the external world. The world we see, the world in which we each live, has only a subjective or internal reality. We translate this subjective reality into what we think the external world is *really* like.

Things and events certainly exist independently of the human mind. But we can know them only as we can perceive them. In fact, within our experience, their ex-

istence is identical to our perception of them. If a person who has been blind since childhood suddenly has his sight restored by shock or surgery, he is, at first, unable to recognize persons or objects or shapes. What he receives through his newly functional eyes is a chaos of sensory signals. He has to learn to perceive things; his mind has to learn to form pictures, to shape a reality out of the welter of sensory signals being poured into his brain. In a person whose eyes have been normal since birth, this process of learning to form a reality is spread out over many years. Sometimes a small child will announce in a desperate voice that he cannot find his pyjamas, even though they are lying on the bed before him. The truth of the matter is that he cannot find them; he has not learned to perceive them. His mind, as it were, has not learned to interpret the signals sent in by the eyes so that these signals become identified as a pair of pyjamas.

A coherent picture of the world around us is formed from sense perceptions coming into our minds from the outside, and also from the apparently non-sensory functioning of the mind itself. The latter we call intuition, or insight. Intuitive knowledge is just as real to us as direct sensory knowledge. But what one person knows intuitively, another person may question, or even flatly deny. They may discuss, persuade, and argue at great length and with much vigour and emotion; but without finding any way to bridge the chasm that lies between their two worlds. When someone says, 'Joe and I see eye to eye in this matter,' it means that two individuals have found at least one point where their worlds are in agreement. Different people look at things differently, according to the kind of reality they know – optimists, cynics, fanatics, and pessimists are but a few of the extremes.

What, then, is reality? In the external universe, the

objective world, what is real? The world of our experience seems very real, but we know that it is a synthetic world that we have formed in our minds from the impressions made by the objective universe. Whatever we perceive we have the individual right to call real, for reality to us must be identical to our perceptions of it. This discussion may seem abstract and a little confusing. The problem of what is real and what is unreal is an abstract subject. It is a question that has been studied by some of the world's greatest philosophers. Their separations of the 'real' from the 'unreal' have proved to be inconclusive, on the whole. The boundary between objective reality, whatever it may be, and a personal subjective reality is not at all clear. It is not clear, simply because we must deal with an external world from within the confines of an internal, subjective sense of reality. And we have no way to escape.

Science is a body of knowledge which represents a prolonged and ever-continuing effort to form a concept of reality which will stand in some sort of consistent working relationship with the external world. Science is objective knowledge, which is to say that, as far as is feasible, it is knowledge of the world which is external to the human mind. This kind of knowledge is an attempt to understand the world of nature both for the sake of knowing what is going on, and to find better ways of controlling and exploiting it. Of course, scientific knowledge cannot be identical to the external world, but must give us the basis of a perceived reality which is consistent with the unknowable concrete world which is independent of the mind of man. Science is an attempt to formulate an understanding of nature which is not dependent on the individual, but can be held in common by all men. To that extent, it can be objective. Thus, science is less subject to

the inconsistencies, vagaries, and incapacities of the individual intellect. It is, of course, limited by whatever shortcoming may be inherent in the minds of all human beings. The evolution of scientific theories is an evolution of reality; it is an evolution of one aspect of social intelligence.

What sort of concept of objective reality is developed in science? The simplest possible. The attitude is that anything which we can measure, any phenomenon for which cause and effect relationships can be demonstrated, has an objective reality. Any thing, any force, which cannot be dealt with by the methods of science has, officially, no objective importance. In every-day experience and in scientific work we have no reason to assume that there are in the external world real things which we cannot detect. There may be many such things, but it is idle (and dangerous, from a scientific standpoint) to assume their existence until we are able to perceive them. Either directly or indirectly, they can be perceived only when we can reduce them to some sort of sense perception – sense data, as it were.

Science is full of all sorts of examples of things we now consider very real, which were undreamed of years ago. Seventy years ago, radio waves were first produced in a laboratory. The existence of such electromagnetic waves had been predicted deductively years earlier by the brilliant Scottish physicist, James Clerk Maxwell. Radio waves are very useful to us, as everyone knows, but it was once thought that they were strictly a man-made force. It is now known that large quantities of radio waves reach the earth from outer space. The radio bombardment from space has resulted in radio-astronomy, an important addition to man's oldest science. Our perceived reality is accordingly more nearly complete. Many other scientific

discoveries have widened the horizons of our ideas of objective reality. Infra-red, ultra-violet, X-rays, vitamins, photons, and a great host of other things have been brought into our experience with the advance of science.

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If science is to be objective, it must rest on a minimum of personal interpretation and be on a basis on which all men can agree. This brings us back to Lord Kelvin's statement which was quoted at the beginning of the chapter. Precise measurements on a scale understood by all removes the personality of the observer, and provides a basis for some degree of objectivity. If this be true, science is a restricted kind of knowledge. The restriction arises from the rigid and exacting requirements of the scientific method.

The importance, and perhaps the tragedy, of eliminating the individual interpretation may be illustrated by a simple example from an area of interest lying outside of science. Let us suppose that a group of people are listening to César Franck's D-minor Symphony. As the majestic strains roll through the room, each member of the group hears a somewhat different piece of music. What is heard in each case is called Franck's symphony, but what sort of reality the music represents depends on many things. To one who has some appreciation of classical music, listening is a stirring emotional experience. To a musician who has studied Franck's works in detail, it is a problem in technique and self-expression, as well as a thing of beauty. To one who does not like classical music, it is nothing more than a complex noise. To him, listening is an obligation, not a privilege. To each member of the group, the symphony has a different beauty, a different meaning, and constitutes a different sort of subjective phenomenon.

These differences have nothing to do with the symphony as it was conceived and written by César Franck. The differences have to do with the temperaments, tastes, educations, and experiences of the individual hearers.

There is no basis on which all of the listeners can agree on the beauty and meaning of the symphony. These are subjective aspects, and differ widely from one individual to the next. The group of listeners can, however, reach a common understanding of the more objective aspects of the symphony. Setting the concepts of beauty and meaning aside, as having no relevance to the problem at hand, they can reach agreement on the structure of the symphony. They can easily agree on measurements of the number of movements, the number of notes, the sound frequencies, the rhythm patterns, and so on. An agreement can be reached only by making measurements of form and dimensions on a scale of measurement agreed to by all.

The symphony as a beautiful musical creation has been replaced by a family of measurements describing the anatomy and mechanics of the music. The measurements have been abstracted from the musical creation, and form an objective concept of the reality of the symphony. But one important thing has been accomplished; a basis for a common understanding has been found. This represents an advance in human understanding, provided that we do not lose sight of the original symphony and claim that it is of far less significance than the measurements made.

Science is not involved with symphonies, but the analogy can be extended to all things we do study. The scientist, in studying the world of nature, is involved in making measurements of form, history, activities, relationships, and processes. The measurements are quantities which are abstracted from the things and events we study. They are made the basis for a useful and understandable

knowledge. To have a knowable, objective reality on which all men can agree, we must reduce thunderstorms, rose petals, rocks, and stars to groups of measurements. The reality of science is a reality of quantitative relationships; a universe of pointer readings on measuring instruments, as Sir Arthur Eddington, a British physicist, once pointed out.

Some things which we normally think of as being qualitative can be measured quantitatively and thus be included in scientific schemes. The qualities of colour, sound, hardness, shape, density, and many others are some of the properties that can be measured just as well as the properties of weight, dimension, and time. Suppose that we have about fifty small glass bottles, each containing a different mixture of a red and a blue dye. We ask a number of people to arrange all the bottles in a row, such that the 'reddest' bottle is on the right, the 'bluest' bottle is on the far left, and all of the intermediate shades are to be placed in the proper order between these two extremes. There would probably be some disagreement among the persons attempting to arrange the bottles. This lack of complete agreement would be caused by their having slightly different visual acuity and slightly different ideas about the qualities of redness and blueness. By using a light-measuring instrument called a spectrophotometer, a trained technician could arrange the bottles in their proper order, quickly and without error. From the pointer readings on his instrument he could not only determine the proper order of the bottles, but could also calculate the amounts of red dye and blue dye in each bottle. He could also inform us of some of the features of the chemical structure of each dye. This technician need not see the colours himself; he might even be completely colour blind. It would make no difference to the measure-

ments, for the qualities of redness and blueness have been replaced by a group of pointer readings on a machine. With these we can deal quantitatively and mathematically; with colours we cannot.

A meteor flashes across the black autumn sky. Its fiery trail hangs for a moment, fades, and is gone. Its brief performance was thrilling to see, but it did nothing that could not be measured and reduced to a cause-and-effect chain of events. A chunk of matter rushing through space at a speed of thousands of miles per hour was deflected from its course by the gravitational field of the earth. As it entered the upper layers of the atmosphere, constant collisions with billions of gas molecules increased the molecular activity in its surface layers. This heating effect increased rapidly until energy was given off as light. As this process continued, the meteor was burned up and its matter dispersed in the atmosphere. By spectrographic analysis of the light produced, the chemical elements contained in the meteor could be identified. From the light path, the approximate size, speed, and course of the meteor could be determined. The brief show of the meteor can be reduced to a cause-and-effect chain of events. And each one of these events can be measured, and their mathematical relationships can be calculated. We know, too, that if another meteor lurches into our atmosphere, the same sort of a series of events will occur. From a scientific standpoint, we understand the meteor because its behaviour has been reduced to a series of measurable and predictable events.

Inches, pounds, grams, dynes, ergs, ohms, seconds, and a host of others are the units in which the universe is measured. All of these units are precisely defined according to standards which have been agreed upon over the years. A dyne in a laboratory in Bombay is exactly the

same unit of measure as in a laboratory in Dublin. A dyne is that force which will produce an acceleration of one centimetre per second per second in a one-gram mass. Only through such standards of measurement is science able to remain objective and world-wide. It is obvious that science would become chaotic and extremely limited if each scientist or group of scientists made up separate standards.

So great has been the success of science in exploring the mechanisms of the natural world that a monumental body of quantitative knowledge has accumulated since the seventeenth century. The progress since 1900 has been truly fantastic. This great success has resulted largely from the fact that the results of quantitative investigations are easily communicated. A natural phenomenon can be isolated and measured. It can be broken down into its several components, and the relationships of the parts, one to another, can be described mathematically. The results of observations and experiments can be tabulated and analysed. Through the pages of scientific journals, the results and the interpretations made can be passed to others. Other scientists can repeat the experiments and elaborate on them, to confirm or deny the original conclusions, and to carry the work still farther.

Science is knowledge of the mechanisms which operate in the objective external world. We can know the world which is external to our minds only indirectly. In this regard, even science is indirect knowledge. Scientific theories and concepts are attempts to form workable ideas of the world which will give us understanding of it and power over it. As our science grows and our ideas become more refined, it is likely that our understanding of the world becomes more accurate. What we know of the real world must approximate to what is really there, as a glove

fits a hand. But we must always realize that the glove is not the hand. No matter how well we make the glove fit, it can be no more than an approximation of the shape of the hand.

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The universe as it was known by physical science in the nineteenth century was a neat and orderly thing. The laws of physics as created by Isaac Newton had been developed, tested, and extended by the work of many physicists. They were found to be admirably suited to account for nearly all aspects of the material universe. Nothing had been found which would cast any doubt on the infallibility of cause and effect. The universe appeared to be a giant machine, set in motion by an unknown force at some unknown time in the past. The history and future of the universe were unchangeably determined from the beginning. The stuff out of which things are made – matter – was also no longer very mysterious. Matter was composed of atoms, and atoms were indivisible hard balls – the ultimate units of reality. Different chemical elements were made of atoms of different sizes and, therefore, weights. Hydrogen was made up of the very smallest atoms, whereas an element like lead was composed of larger, heavier atoms. Time, space, matter, and energy were all separate entities which were woven together to form the universe. There was some difficulty in fitting the properties of light and electromagnetic forces into the universal concept. It was thought, however, that this difficulty could be taken care of by assuming that the space of the universe was filled with an intangible stuff called ether.

Biology was not so well developed as physics, but it was felt that the living organism could also be considered as

a machine. The material body of an organism must be constructed out of atoms, the same as everything else. Since this was obviously true, the same concepts of time, space, energy, and matter must be as applicable to the living as to the non-living. If everything that occurs can be reduced to a measurable series of events, related to each other in a cause-and-effect way, plants and animals must also be included in that 'everything'. Biologists were busily engaged in problems of evolution, using the new theory of Charles Darwin. Evolution by natural selection fitted into a mechanical, casually determined universe in a neat and gratifying manner. Of course, nothing much was known about heredity. This ignorance made it a little difficult to see just how natural selection actually works. An obscure Austrian monk by the name of Gregor Mendel had discovered the basic laws of genetics, and had published his findings in 1866. But his results were ignored, and in 1900 they were 'rediscovered'.

The late nineteenth century was an era of complacency. In technology as well as in science, there was a growing feeling that man had advanced about as far as he needed to, and that the end was in sight, or at least was predictable. A high official in the U.S. Patent Office resigned his position because he thought that there was no future in patents. *Everything* had been invented and duly patented. Physicists had what they thought was a reasonably complete scientific concept of the universe. Lord Kelvin, an eminent physicist, announced that he could not accept any idea as scientific unless he could either visualize or construct a model of it. Although it might take many years to fill in the needed and useful details, all of the fundamental scientific knowledge was complete. It was now largely a matter of tidying up the workshop before locking the door.

Just before the turn of the century, it was discovered that there are particles which are much smaller than hydrogen atoms. The existence of the tiny particles was shown by passing an electric current through a vacuum in a glass tube. It was shown that the particles were less than a thousandth the size of hydrogen atoms, and that they were electrically charged. They were therefore called 'electrons'. The property of the electron which made it unique in science was that it was found to be nothing but an electric charge. It behaved like matter in the classical sense, in that it had both mass and inertia. But its mass was found to be due entirely to its electric charge. Without the charge, it had no mass, no substance. The electron was found to be a particle of electricity. This was the opening gun of the twentieth-century revolution in physical science.

Why was the electron so revolutionary? It was the first clue that led to the idea that matter and energy are basically one. Here was a bit of stuff that acted like both matter and energy, and did not fit into the concept of atoms being like hard little marbles. A different way of thinking about both matter and energy was to be grasped. A new approach to old problems became a possibility. Naturally, the present-day concepts of matter and energy did not spring into being immediately upon the discovery of the electron. Science does not advance so recklessly. The work of many men had to come first, and some challenging frontiers of thought had to be explored and developed. According to an old Chinese proverb, a journey of a hundred miles begins with but a single step. The electron was the first step on a journey that would change the shape of science and remodel the known universe.

Quite rightly, the discovery of the electron did not at first greatly change scientific ideas on the construction of

matter. The electron was simply a particle of electricity, and it had to be included in science with a minimum of disturbance to well-established ideas. Since it was known that whole atoms carry no electric charge, the negative charge of the electron must, by necessity, be neutralized by a positive charge on the rest of the atom. Sir Ernest Rutherford showed that the atom is composed mostly of space. These advances gave rise to the concept that an atom is like a little solar system, in which negatively charged electrons travel like planets in orbits around a large positively charged nucleus. The structure of the atom could be visualized, and a model could be constructed.

Measurements and calculations indicated that there is really very little actual 'matter' in an atom. If the space between the atoms and within the atoms contained in a human body could be compressed so that all the particles were touching each other, the unfortunate compressed person would be so small that he would be just barely visible. The solid matter, the hard marbles of the nineteenth century no longer fit the picture very well. Such a concept of solid matter became a little difficult to maintain. Without tracing the development of modern atomic physics, it is sufficient to say that we now know that the atomic nucleus is also composed of particles which are indistinguishable from quantities of energy. We also know that the human body we suggested be compressed almost to invisibility would, were such compression possible, explode like a bomb.

A mental picture may be formed of an atom as consisting of a nucleus, or central body, with one or more electrons circling around it in orbits. Such a model would seem acceptable enough, even though we must abandon the idea that the larger particles constituting the central

nucleus and the smaller electrons are solid matter in the sense that a rock or a crystal is solid to touch and sight. The only trouble with this way of imagining what matter looks like is that it is not good enough. Experiments with electrons, X-rays, photons, and other such tiny subatomic specimens, have shown that they behave like waves as well as discrete particles.

If one drops a pebble into a pool of water, waves or ripples travel along the surface from where the stone struck. The waves are a sort of disturbance that spreads out and is slowly dissipated. Sound waves are also such disturbances, except that they are carried by air instead of water. Light has long been known to have wave properties. Because we cannot think of waves without some sort of a carrier, the question of how light manages to travel through empty space was long a vexing problem. As we have already seen, the idea of ether was used to provide a solution to this problem. We now know, however, that light is in the form of little units or particles, called photons. Photons are particles in about the same sense that electrons are particles, and they travel in a wavelike manner. Electrons also are in constant motion, and travel along a wave-shaped path.

And right at this point, we must give up the mental picture we had of electrons moving in orbits like planets around a sun. An electron does not behave like a particle moving in a wavelike manner; it acts like a particle and also like a spreading wave. An electron in an atomic orbit cannot be located as a discrete particle, and we have to think of it as a sort of wavelike disturbance in an orbit around the atomic nucleus. We must not think of such waves in terms of an ether-like carrier, either. An electron may jump from one orbit to another, an occurrence which is accompanied by the release of a photon when the shift

is to an orbit closer to the nucleus. The strangest part of this performance is that the move from one orbit to another appears to happen suddenly, and the electron does not appear to travel through the space between the orbits. In other words, the electron's shift to a different orbit is instantaneous and does not involve moving a material particle through space. This seems to be the sort of concept required to account for the observed properties of electrons and other subatomic entities of that general ilk. It does not appear to be possible to form a mental image of such an atom, and the whole concept is very far removed from that of the nineteenth century.

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The work with waves, energy, and particles has tended to make us wonder about how understandable nature really is. It is apparent that these things are not understandable to the extent of being easily visualized, and an understanding is attainable only through mathematical expression. From such advanced physical studies, there has come a very disquieting result known as the *principle of uncertainty.* This principle appears to throw some doubt on the concept of cause and effect. We must be very careful, however, about deciding just how this uncertainty affects our thinking about chains of causally related events. This is an extremely important matter for, as has already been pointed out, science is a body of knowledge based, in part, on the assumption that cause and effect are fundamental characteristics of the universe. So let us make a brief examination of the principle of uncertainty.

The principle says in effect that we cannot observe and measure the course of natural happenings without in some way disturbing them. Thereby we introduce at least a small amount of uncertainty as to what goes on naturally.

At a gross, large-scale level, this disturbance is unimportant, but at the level of atomic particles it becomes of great significance. By refining our techniques of measurement, we can reduce the uncertainty, but we can never eliminate it entirely. There is a degree of uncertainty which can never be avoided. Suppose that we wish to determine the position and velocity of a rifle bullet a fraction of a second after it leaves the muzzle of a gun. This would be a technical problem of no insurmountable difficulty. A high-speed camera and precise timing devices would be required. At a measured time after the gun was fired, a series of pictures could be taken. By knowing the position of the camera and the time interval between successive pictures of the bullet, a good estimation could be made of the bullet's position and velocity. From these data, the entire path followed by the bullet from the time it left the muzzle until it fell to the ground could be calculated quite accurately. It certainly would not seem that our observations had in any way disturbed the bullet. Nor would it seem likely that our observations had introduced any degree of uncertainty as to the position, velocity, or trajectory of the bullet. To be sure, we had to shine some light on it in order to take its picture a few times as it streaked past the camera. Considering the infinitesimal size of light particles, compared to the size of the bullet, it is quite safe to assume that bombarding the bullet with light had no measurable effect on the bullet's behaviour.

Electrons are different from rifle bullets. If the speed and position of an electron were to be determined in the same sort of way, some insurmountable difficulties would be encountered. An electron, fired from some sort of an electron gun, could be detected only by its striking some other particle. Of course, the same is true of bullets, and there we used a stream of light particles. A photon, a unit

of light, is a relatively large particle to slam into an electron. Striking an electron with light would deflect the electron from its original path into an unknown course and would give it a new speed. Collision with a light particle might give us a determination of the position of the electron at one moment only, but it gives us no information on the electron's speed. Other means may be devised to measure its velocity, but we cannot then know its exact position. Since we have no way to measure both speed and position on the same electron without causing a change in one or the other, we cannot predict its position or speed at any time in the future. The most notable thing about this uncertainty is that it is a difficulty which will hamper all future work; it is not a mere technical quandary that a new technique will solve. Thus there is a permanent degree of uncertainty involved in such attempts to follow the course of natural events.

It may not be at all clear how the degree of uncertainty, inescapable with very small particles, can have any effect on the ideas we have concerning cause and effect. Description of a chain of events as a cause-and-effect series requires that we be able to observe that chain of events continuously from start to finish. This enables us to describe just what is the state of affairs at any given time. In the case of measuring the path of a rifle bullet, continuous observation is at least theoretically possible. The bullet is an event which may be followed without appreciably disturbing its action. In the case of an electron, continuous observation is not possible, because its behaviour is changed by the very means we must use to observe it. If we detect a particle at point A at one moment and at point B the next moment, we have no way of knowing whether we have observed one particle or two. And in some ways it is better if we do not even entertain the

question of continuity, but simply consider each observed particle as a separate isolated event.

Just because we cannot measure it, are we justified in denying the existence of cause and effect on an atomic level? No, it may well be that nature is always in accord with cause and effect, and that nothing happens by chance or without previous cause. The infallibility of cause and effect has been destroyed from a scientific standpoint, however, because we have reached a point where the concept cannot be tested. Any idea that cannot be tested must be dropped from science, as it becomes a purely philosophical question. This does not mean that the whole idea of cause and effect is to be dropped. It is still very useful, and it still plays an important role in the observations, hypotheses, experiments, and conclusions in most branches of science. The breakdown of cause and effect in dealing with the ultimate units of matter-energy serves to show us that there may be other doors to understanding, other worlds not dreamed of in our present scientific schemes. What we observe, what we measure, what we think we know of an objective reality depends in large part on how we go about measuring it, and may be only a poor approximation of what really is.

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At the beginning of this chapter, we set out to determine what sort of a world is described by science. The goal was to draw a picture of an objective scientific reality. From the outset it was apparent that the whole idea of reality is an elusive, personal sort of thing, and that knowledge even approaching objectivity has to be in the form of measurements of some sort. The most exact and communicable measurements are mathematical. The most meaningful measurement from the standpoint of scientific explana-

tion is a description of cause and effect relationships, expressed in terms and language of mathematics. When it is possible to describe a series of events in terms of cause and effect, and when we know enough about the subject so that accurate predictions can be made as to the course of events under different conditions, we say that we have a scientific understanding of it.

The assumption that everything, every phenomenon, can be accounted for as the effect of measurable causes has turned out to be too naïve; at the level of the ultimate particles of physical reality, we find that we are unable to follow the trail of cause and effect. Another naïve assumption that has been part of science is that objective reality consists of nothing more than the ultimate particles of matter-energy and the space-time in which they occur. The attitude has been that the objects we see and identify in our day-to-day living must owe their physical properties to the characteristics and behaviour of the material particles composing them. This is, of course, a strictly materialistic attitude, but science is knowledge of a physical, material universe. If the expectation is that we should be able to account for our whole world of reality on the basis of the behaviour and properties of point-events, such as electrons, we are almost certain to fail.

Any object, any event, which may be observed and measured has, from a scientific standpoint, some sort of objective reality. It is one of nature's facts, and it must be accepted as real. It is, after all, the raw material for scientific research. The sort of knowledge we gain of it, the sort of reality we assign to it, depends largely on how we study it. It depends on what sort of scale we use to measure and observe. If we wish to study the process of photosynthesis, we must work at a molecular and atomic level, because that is the level at which photosynthesis

occurs. We are then involved in measuring how plants utilize light energy to combine molecules of carbon dioxide and water to produce sugar. The questions we ask are concerned with transfer of energy, atomic behaviour, and molecular synthesis. The scale of observation we use must be one where atoms, molecules, electrons, and action quanta have meaning and reality.

But if we study a complex problem, such as animal behaviour, it is difficult to determine the scale of observation that will be the most meaningful. For example, suppose we are curious to know how it is that a moth will fly into a candle flame. We can study the problem grossly and then in more and more detail by changing our viewpoint, or scale of observation. First, we can show that such behaviour does, in fact, occur, simply by releasing a moth in a room which is dark, except for one small light. The moth will fly to the light, and we know that this behaviour does occur. It is the real fact which forms the starting-point of the investigation. We do not yet know how it occurs, or why it occurs, but we do know that it does occur. Now, we can find out a little more about the behaviour by repeating our first observations, except that on different trials we will use lights of different wave lengths (colours to us). We will thus find out what kind of light is most efficient at inducing the behaviour. If we should cover the moth's eyes with a thin layer of opaque paint, we will find that the moth no longer flies toward the light. We now know that the eyes are involved in the behaviour we are studying. Thus far we have been working on a rather gross scale. But to follow the chain of events further, we must go to a lower scale of observation, and start experimenting within the moth itself.

By the delicate operation of cutting the nerve tracts between the moth's eyes and brain, we can show that

nerves and brain are associated with this particular behaviour. By similar operations, we can demonstrate that nerve pathways from brain to the big wing muscles are involved. These observations have been on an anatomical scale of measurement. By the use of suitable instruments, we can show that nerve impulses are involved, and that nerve impulses are associated with electrochemical changes in nerve cells. We can also show that the wing muscles are activated by nerve impulses. Muscle action involves contractions, an occurrence requiring energy. Energy to make muscles work is obtained from a metabolism of sugar.

The study of a moth flying to a light has resulted in the description of a chain of cause and effect events involving light, eyes, electrochemical impulses of the nervous system, muscle contractions, and energy metabolism. In describing this chain of events, we have used several scales of observation, in which we got progressively farther away from the specific problem we set out to investigate. At each level we observed and measured occurrences which were no doubt real. But their reality seemed less and less directly applicable to the problem of why the moth flies to the light. We do not doubt the prediction that a poison which would inhibit the moth's energy metabolism would also stop its flying to a light. We cannot predict in the other direction, however, for there is nothing in energy metabolism which would enable us to predict that the moth would fly to a light. We have described the behaviour as a mechanism, with the moth as the carrier of that mechanism. The mechanism can be studied from many different points of view. But we cannot, from the ultimate details of the mechanism itself, predict the original observed behaviour.

A biologist who is a specialist in behaviour might object

to this description of the cause-and-effect sequence involved in the flight of the moth. Behaviour, he would say, does not start in muscles. Behaviour patterns are controlled from within the nervous system. The characteristics of an animal's behaviour are determined by nerve pathways, association centres, and so on. Nevertheless, whichever chain of events is followed, we reach a dead end at the energy and subatomic levels, whether in muscles or in nerves. Phenomena such as animal behaviour do not take place at an atomic level; they occur in a much more complex and highly organized state of affairs. In describing behaviour as merely one link in a measurable chain of events, we are left with some doubt as to whether some of our measurements have any bearing whatsoever on the problem at hand.

We have studied the universe and have found it to be constructed of elusive particles. From the uncertain behaviour of these particles we cannot reconstruct the reality we know. The real things and chains of events that make up the world appear to be more than just bits of matter-energy; reality is a highly organized thing. The characteristics of that organized reality depend on how we study it, the tools and methods used. It is no longer sufficient to think only in terms of cause and effect, mere chains of events. Our intellectual horizons must become broader if our science is to continue to advance in scope and meaning.

6

TAKE A CHANCE

'If we begin with certainties, we shall end in doubts; but if we begin with doubts, and are patient in them, we shall end in certainties.' *Francis Bacon*

A GROUP of young men have arranged themselves in a circle. Each is kneeling, and each is intent in watching one member of the group. This young man performs a ritual with two small white objects. The men are all dressed in identical blue uniforms. When the performing member casts the white objects to the ground, the others shout and gesticulate and exchange money. If we move closer to the group in order to study this odd behaviour, we see that it is a group of sailors. They are engaged in the time-honoured but unsanctioned custom of shooting craps.

Craps is a gambling game played with a pair of dice. A crap game is not a scientific event; it is a game of chance. Though science is not involved in crap games, there is considerable scientific importance to the principles of the game. Craps is a game of chance, but the wise player plays the odds in order to leave the game with more money than he brought into it. In many areas of science we find that there is a large element of chance in natural phenomena. Our scientific research, then, is somewhat like a gambling game, and to leave with more information than we brought into it, we must, like good crap players, learn to play the odds.

The individual characteristics of plants, animals, and

humans, too, are passed down from generation to generation via hereditary units, which we call genes. The genes of each individual number in the thousands, and each kind comes in pairs. Each of the two parents contribute only one of each of their pairs of genes, so that the offspring likewise has its genes in pairs. It appears to be largely a matter of chance as to which particular genes are given to a particular offspring. This sort of random shuffling and dealing of genes makes it necessary to incorporate concepts of probability, or chance, into the biological science of genetics.

In almost any scientific experiment we do not get precisely the same results every time the experiment is conducted. The experiment being conducted may be a very simple matter of measurement, such as determining the time it takes for an object to fall a given distance. Or the experiment may be more complex, as perhaps in determining the effects of a tranquillizer on the heart and central nervous system of an animal. In either type of experiment, measurements of some kind are made; and the results are always checked and rechecked by running the experiment several times. Experiments are not perfect, and neither are experimenters. So the measurements made will vary a little bit from time to time, in spite of every attempt to maintain standardized conditions. Some small variations in the results may be due to chance alone. Some variations, however, may be important errors resulting from poor technique, improper controls, or other unknown factors.

A means is needed for determining whether experimental differences are the result of chance, or whether the differences have real meaning. For this purpose, statistical analyses are used, and the probability of experimental results being nothing but random or chance happenings can be calculated. Statistics is a mathematical study of

probability, and is a powerful tool in science. Statistical analysis will not interpret experiments for us; it will tell us only what the chances are that our results can be interpreted at all. This is an important thing, however, and makes the study of chance quite significant in science.

As we will see in more detail later in the chapter, in the realm of subatomic physics, probability mathematics has come into great prominence. This emphasis on probability has come about simply because in working with these very small particles, we have had to abandon strict cause-and-effect ideas, as was pointed out in the last chapter. If cause and effect cannot be detected or measured, random activity or pure chance seems to be the only alternative interpretation which will allow us to develop workable concepts. It seems that probability is to play a big role in the shape of scientific knowledge. An understanding of the general principles involved is, therefore, important in our exploration of the structure of science.

Then let us set these matters of science aside for a little while and see what can be learned from playing with a pair of dice. Examination of a single die shows us that it is a cube, with each of its six sides identical in size. We also observe that each side is marked with a number of spots, ranging from one to six, without omission or duplication. If we drop the die on the table, it always comes to rest with one of its six sides uppermost, and thereby displays some number between one and six. This it does every time that it is dropped or rolled; there is no possibility of its failing to do so; it will happen every time. We can express probability as a numerical fraction made up of the number of successes divided by the number of attempts. In the case of a certainty, the number of successes is equal to the number of attempts, and the probability equals $1/1$ or 1. Since the die does not have a blank side nor a side with

seven spots, there is not the slightest possibility of rolling a zero or any number higher than six. The probability of such an impossible event is $0/1$ or 0. The range of probability for any system whatsoever is from 1 (certainty) to 0 (impossibility).

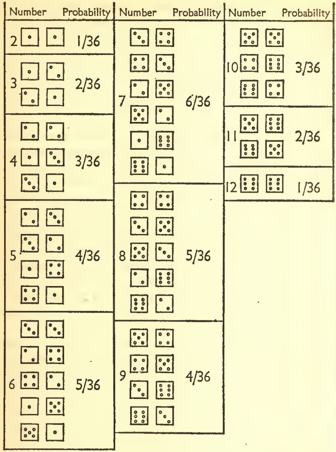
Since the die has six equal sides, there is no way of predicting which side is going to turn up when the die comes to rest. There is no reason to believe that one number will turn up any more often than another number. There are six possible numbers, and it is certain that one of them must turn up. Each particular number should turn up in about $1/6$ of the rolls, therefore. If we roll the die 1,000 times, each number from one to six should have shown up about 166 times. The probability of rolling any particular number is $1/6$. The probability of rolling a four is $1/6$. Suppose that we roll a four; what is the probability of rolling another four on the next toss? It is still $1/6$. Dice have no memory, and probability is not based on a retroactive 'law of averages'. If we have not yet rolled the die, what is the probability of rolling four twice in a row? The probability of the first four is $1/6$. The probability of the second four is one sixth of one sixth ($1/6 \times 1/6$), which equals $1/36$. But if the first four is accomplished, it immediately drops out of consideration, and the probability of the second four is the same as for any other number between one and six, namely $1/6$.

Now let us add the other die, so that we are playing with a pair of dice. The situation becomes more complicated than it was with just the one, but it is still relatively simple and easily understood. In the first place, it must be seen that each die is independent of the other, and everything that was said about one die in the preceding paragraph applies to each. What we are now interested in is the combination of two dice, at least to the extent of

adding the numbers that turn up on each die each time that they are rolled. It is a certainty that two numbers must turn up at each toss, and that neither of the numbers can be less than one or more than six. It is obvious, then, that the combined total must always be between two and twelve. Where each die must show any one of six numbers, the possible specific combinations of numbers with two dice is 6×6, or 36.

The chart shown on page 114 pictures all of the possible dice combinations. The probability of rolling any one of these specific combinations is, of course, 1/36, since it would be only one of the thirty-six possible. A combined number shown by the dice will have a probability of from 1/36 to 6/36, depending on the number of specific combinations which will total that number. Looking at the chart, we see that there is only one combination which will give a total of two (snake eyes in gambling parlance). The probability of rolling such a number is, therefore, 1/36. Seven, on the other hand, can be rolled six different ways, and its probability becomes six times 1/36, or 6/36. Examination of the chart will show that the probability of rolling any given number is determined entirely by two numerical factors: (1) the total combinations possible, which is 36, and (2) the number of possible combinations which will total the desired number. The probability of rolling a seven is 6/36, which as a simple fraction can be reduced to 1/6. The probability of rolling a ten is 3/36, or 1/12. It is easily seen that the probability of rolling a seven is twice as great as the probability of rolling a ten.

What is the probability of rolling a seven five times in a row? It is $1/6 \times 1/6 \times 1/6 \times 1/6 \times 1/6$, which equals 1/7,776. This is indeed a very small probability. Suppose that we try to roll seven five consecutive times, and on the first roll a seven turns up. So far so good. The probability



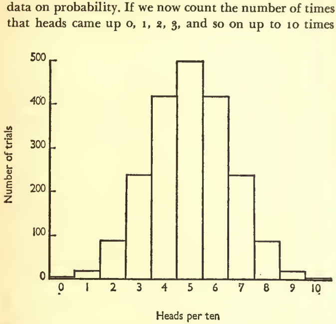
of completing the series is now $1/6 \times 1/6 \times 1/6 \times 1/6$, which equals $1/1{,}296$. If another seven is rolled, the probability of completing the series becomes $1/6 \times 1/6 \times 1/6$, or $1/216$. The important thing to notice here is that the probability is based on the likelihood of a future event,

and has nothing to do with what has happened in the past. So that, if we did happen to roll four successive sevens, the probability of rolling still another seven is simply 1/6. Another feature to be learned about probability can be illustrated by the chances of rolling the number two on five successive tosses. The probability of rolling a two is only 1/36, compared to 1/6 for a seven. The probability of rolling five twos in a row is $1/36 \times 1/36 \times 1/36 \times 1/36 \times 1/36$, which is equal to 1/60, 466, 176. Rolling five twos in a row has a probability only 1/7,776 as great as the probability of rolling five successive sevens. Rolling such a series of twos is highly improbable, but it is not impossible. An event is impossible only when its probability is zero.

The situation becomes more complex if we start playing with three, four, five, or more dice. Regardless of how many dice are used, the same probability principles are involved, and the complexity is merely one of difficulty of mathematical manipulation. Similarly, the same basic ideas apply to a system which is simpler than dice – flipping a coin for heads or tails, for instance.

Let us look briefly at this business of flipping coins, for it illustrates another important thing about probability. When you flip a coin, it must come up either heads or tails. The probability for heads is the same as for tails; that is, 1/2. If you flipped a penny ten times, you would expect it to come up heads about half of the time. And in the long run it would. However, anyone who has tried flipping pennies knows that, out of ten trials, heads does not always turn up exactly five times. The penny may come up heads four, six, or two times, or not at all in ten tries. Or heads might turn up all ten times. Suppose that we flip a penny ten times and make a note of how many times heads came up. Then we flip it another ten times and

again jot down the number of heads. We keep repeating this performance until we have done it 1,000 or more times. Besides having a tired thumb, we will have a lot of data on probability. If we now count the number of times that heads came up 0, 1, 2, 3, and so on up to 10 times

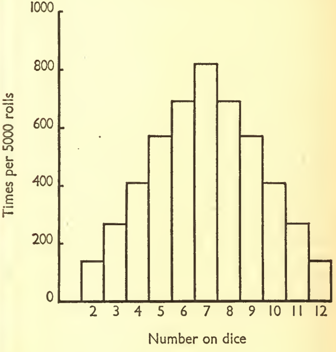


out of ten flips, we can make the counts into a graph that looks like this:

A graph of this belllike shape is called a *normal distribution*, and is very valuable in the study of probability. What is so important about it? It is important because it is a measure of the variation that we can expect to find among events which happen purely by chance. The probabilities assigned to events such as flipping heads with a coin or rolling a seven with a pair of dice, represent the expected averages. The normal distribution graph tells us

something about variations around that average. A number of exceedingly useful statistical concepts are based on the properties of the normal distribution.

From very simple probability concepts, such as were



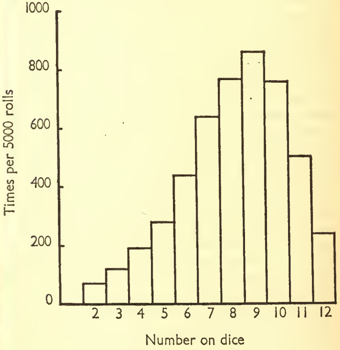
illustrated with dice and pennies, a complex mathematical system has been developed. This body of mathematics is known as statistics, and plays an important role in our economy as well as in science. In order to get an idea of these applications, let us go back to the pair of dice. We shall assume that our pair of dice has been checked care-

fully and is perfectly balanced and in every way uniform. We now roll the dice 5,000 times and record the numbers which turned up each time. From that record, we can make a graph of how many times each number from two to twelve turned up. The graph (illustrated on page 117) will show us that the total times that each number occured was in proportion to its probability. Seven came up more often than any other number, and, as we have already seen, the probability of its turning up is greater than the probability for any other number.

We now take another pair of dice, a pair whose accuracy or balance we are not sure of. We roll this second pair of dice 5,000 times, also keeping a record of the numbers turning up. This time we find that a graph of the results shows a peak at the number nine instead of seven. Such a graph is shown opposite. The probability of nine is 4/36, compared to 6/36 for seven. With properly made dice, then, nine should show up only two-thirds (4/6) as often as seven. With the second pair of dice, we did not get the expected results, indicating that the numbers were not turning up strictly by chance. The results tell us that some factor was causing the number nine to show more frequently than can be explained on the basis of its expected probability. We immediately suspect that there is something abnormal about this pair of dice. If we should check them, we should probably find that they were not perfectly balanced. This imperfection had the effect of changing the probabilities of the different numbers, and changed the shape of our graph.

Although necessarily more complex mathematically, this sort of consideration is useful in science. It gives us a means of determining the accuracy of measurements and the probable significance of differences we find in experiments. This is done by statistical analysis, which is essen-

tially a matter of determining whether or not different groups of measurements form normal distributions which are different. If all of the data fall into only one normal distribution, it means that they are all part of the same



average value. In that case there are no true differences between groups of experimental results. If, on the other hand, the data form more than one normal distribution, it means that there are true differences in the experiments.

Which of the six sides of a die lands uppermost is a matter of chance. It has no effect on what number turns

up on another die. Neither is it influenced by what numbers have turned up on previous occasions. Nor does it in any way affect what may happen in the future. The tossing of a die is an *isolated independent event*. In many natural occurrences, however, we have every reason to believe that one event leads to another. This gives us the possibility of a chain of events, a cause-and-effect series. In a reaction such as in an atomic bomb, the series of events forms what is called a chain reaction. A large, unstable atomic nucleus, such as in uranium, may suddenly split. Upon splitting, two high-speed particles are flung out of the nucleus. If one of these high-speed particles strikes another uranium nucleus, it will cause that nucleus to split. Consequently, two more particles are sent speeding off. Thus, each such particle may cause the release of two more particles. In a tightly packed arrangement, where few of the particles miss hitting a nucleus, a chain reaction is set going. The production of two particles leads to four; four leads to eight; eight to sixteen; and so on. A series in which the numbers are doubled each time soon leads to fantastically large numbers. The chain reaction in an atomic bomb involves the release of energy, and the rapid build-up of the energy in a confined space results in a horrendous explosion.

The rapid build-up of a chain reaction may be illustrated by a little story about a cowboy and a crafty blacksmith. The cowboy wanted the blacksmith to shoe his horse, but he did not want to spend much money on the operation. After dickering over the price and not coming to an agreement, the blacksmith said, 'Tell ya what. It takes eight nails to put on a shoe. That makes thirty-two nails all together. I'll give you the shoes for free. I'll charge you just two cents for the first nail, four cents for the second, eight for the third. Each nail will cost just

twice as much as the one before.' The cowboy agreed to this plan. When the blacksmith finished shoeing the horse, he presented the cowboy with this bill.

NAIL	PRICE	NAIL	PRICE
1	$0.02	19	5,242.88
2	.04	20	10,485.76
3	.08	21	20,971.52
4	.16	22	41,943.04
5	.32	23	83,886.08
6	.64	24	167,772.16
7	1.28	25	335,544.32
8	2.56	26	671,088.64
9	5.12	27	1,342,177.28
10	10.24	28	2,684,354.56
11	20.48	29	5,368,709.12
12	40.96	30	10,737,418.24
13	81.92	31	21,474,836.48
14	163.84	32	42,949,672.96
15	327.68		
16	655.36	TOTAL	$85,899,345.90
17	1,310.72		
18	2,621.44		

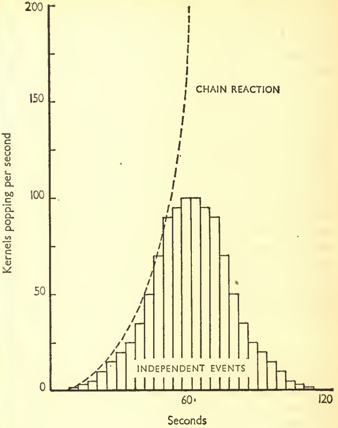
PLEASE REMIT

We see, then, that there is considerable difference between a chain reaction and a series of independent events such as the numbers showing up on a pair of dice. The differences between these two types of events are scientifically important. Offhand, one might suspect that there is little or no element of chance in a chain reaction such as an atomic bomb. Once set going, it runs to completion as a rigidly determined cause-and-effect chain of events. This would tend to make us believe that natural occurrences might be divided into those happening by probability and those happening by cause and effect. To see

how the two types are related and how both fit into a concept of probability, we will have to explore more examples of probability measurements. With them we can find out quite a bit about probability, and also how we have had to change our ideas about cause and effect.

Suppose that 1,000 kernels of popcorn are dropped into a kettle of hot oil. After a little while, the kernels begin to pop. At first it is just one, then several, and then more and more. The popping gets very rapid, slows, and stops as the last kernel explodes into fragrant white edibility. Was this event of popping corn a kind of chain reaction? Or was it a series of isolated independent events? It could easily be like a chain reaction, if the popping of one kernel influenced the popping of one or more other kernels. We can determine whether it was a chain reaction or an independent series by making some measurements. It would not be difficult to devise a means of counting the number of grains that popped during each second of the time that it took for the whole 1,000 to pop. We could make a graph of the counts, as we did of coin-flipping results earlier. If the popping of each kernel was an isolated event, quite independent of what was happening to the 999 other kernels, we should expect to obtain a normal distribution curve. Such a graph is illustrated opposite, and we see that it is the same type of curve as we obtained with the coin flipping. If, on the other hand, corn popping is a type of chain reaction, the frequency curve should rise, continue to rise, and end abruptly. This type of a curve is shown as a dotted line in the graph.

If you wish to go to the trouble of counting and plotting the popping of corn, you will find that it is a series of independent isolated events. The high mid-point of the graph will be the average popping time. The rest of the



graph will show the variation from that average. There will be no indication of a chain reaction. Since the popping of corn is somewhat similar to rolling dice, it should be possible to calculate probability values for it. One could easily mark one kernel so that it could be identified. What is the probability of its being the first kernel to pop?

Since there are 1,000 kernels, the probability of its being first is 1/1,000. And so on, just as with the dice. Although it is an unlikely event, the probability of all 1,000 kernels popping at exactly the same second could be calculated without much difficulty.

The radioactivity of radium, or any radioactive substance, is similar to the popping of popcorn. The breakdown of an atom of radium appears to be a spontaneous thing, and it is not possible to predict just when a particular atom is going to go to pieces. It is possible, however, to predict the general level of radioactivity that goes on in a piece of radium made up of many millions of atoms. The decay of radium is not a chain reaction, but is a series of independent events. The predictions that are made must be based on probability calculations. As with dice and popcorn, such predictions have great statistical strength and may be very precise and accurate. Their precision and accuracy come from the fact that many events of equal probability are involved. They have little value when applied to a single isolated event, however.

*

There are many applications of probability concepts, both in science and in other human activities. Life insurance premiums, for instance, are based on probability calculations. On the basis of what has occurred in previous years, insurance mathematicians can predict with reasonable accuracy the death-rate in particular age-groups of men and women. The more accurate their predictions, the better the basis they have for determining how much to charge for their insurance. They cannot predict, however, just which particular people are going to die. They cannot deal with isolated individuals, only with large numbers of people.

Even though insurance mathematicians cannot predict which individual persons are going to die during a future period, there is no question about death being the effect of well-defined causes. People do not die spontaneously without cause. Death is caused in one way or another – by disease, by organic failure, by injury. Death results from a person's being caught in the gears of some cause-and-effect machine, by either design or accident. The same thing is true of popcorn kernels. The popping is the result of increasing the temperature within the grain; it is in part dependent on the moisture contained in the kernel. The explosion of the kernel is the effect of such causes. And it would not be too difficult to devise a way to measure the internal changes in an individual kernel. It would thus be possible to predict accurately the exact moment that the kernel would pop. The same reasoning can be applied to rolling dice. The position of a die at rest must be the final effect of all the physical forces acting on the die, from its starting position, through its being shaken, and finally being tossed on to a table top. There is little doubt that a machine could be made which could toss the dice so that the same numbers would turn up almost every time.

But in men dying, corn popping, and dice rolling, there are so many factors involved that it is not feasible even to attempt to measure each one. This is especially true where there is a large number of individual men, kernels, and dice to be considered. It is more practical to consider the matter statistically; that is, on the basis of probability calculations. And the strange part of it is that the larger the number of individual events, the greater is the agreement of their behaviour with that predicted on the basis of probability. There are no cause and effect relationships between dice, or kernels, or men in our examples, whatever the factors acting on or within them individually.

It is well established that atoms and molecules are in constant motion. And the more heat energy that has been added to the system, the faster they move. The motion of molecules is apparently at random. They collide with each other, bouncing away again in a direction and at a speed that depends on how they chanced to collide. Each collision and rebounding is an isolated event that appears to be the effect of causes. But where there are many millions of molecules bouncing around, the over-all effect is based on probability.

When you inflate a motor-car tyre with air, the tyre pressure rises and you drive off, literally floating on air. The pressure in the tyre was the effect of a cause; namely, your pushing a whole lot of extra air molecules into the confined space within the tyre. But was it? Tyre pressure is the result of billions and billions of gas molecules rushing about inside the tyre, bouncing off each other and, even more important, colliding with the inside surfaces of the tyre. The combined force of their bumping against the inside walls keeps the tyre from collapsing. The higher the number of collisions per instant of time, the higher the tyre pressure. The exact number of gas molecules that happen to smash into the tyre walls in a particular instant is a chance event, and so is consistent with the mathematical laws of probability. If you inflate the tyre until the pressure gauge records 28 pounds, the tyre will hold that pressure at 28 pounds. The tyre pressure does not fluctuate up and down, as do the numbers rolled on a pair of dice. The reason the pressure holds steady is purely statistical. There are so many billions of molecules rushing around in the tyre that a moment-to-moment difference in a few hundred thousand collisions will not make the slightest detectable difference in the tyre pressure.

Another point to be considered here is that there are

millions of air molecules hitting the outside of the tyre, too. These outside collisions tend to push the tyre inward, toward a reduced pressure and flatness. When the tyre was inflated, unimaginably high numbers of gas molecules were forced inside. This simply increased the probability of there being more molecules pushing from inside the tyre than from outside at any given moment. By sheer weight of numbers, the probability has been shifted. And the tyre-pressure gauge is really only an instrument used to measure the extent to which that probability was changed. Cause and effect? To be sure, but only in the sense of our loading the dice in our own favour. We can make nature's probabilities work for us, and we call it cause and effect, and we ride on air.

The physical laws that we have described concerning the effects of temperature, pressure, and volume on the behaviour of gas molecules may all be based on probability. Just as with the inflated tyre, what goes on in any container of gas can be interpreted as a statistical average among a very large number of independent events. Gas molecules are not so different from other molecules. What happens in other material bodies may also be explained in terms of chance and probability.

A question might be raised concerning an occurrence where a definite change is involved, where two colliding molecules do not simply bounce away again but interact in some way. A chemical reaction would be such an instance. Most, if not all, chemical reactions are much better described in terms of probability than in terms of cause and effect.

Suppose we put a teaspoonful of baking soda into some vinegar. Chemically, baking soda is sodium bicarbonate, and the important part of vinegar is acetic acid. Baking soda reacts with vinegar, and a vigorous fizzing and bub-

bling takes place. Sodium acetate is formed in the reaction, and carbonic acid is also produced. Carbonic acid under these conditions is quite unstable, and it breaks down to form water and carbon dioxide. At ordinary temperatures, carbon dioxide is a gas, and so it escapes from the reacting mixture. The escape of carbon dioxide accounts for the bubbling reaction. All of this may be described in terms of cause and effect. If we follow the course of the reaction, however, we find that it gives us a normal distribution curve, just like the one we got with popcorn. The chemical reaction between vinegar and soda was dependent on collisions of molecules of acetic acid with those of sodium bicarbonate. Whether such collisions occur and how many occur per moment depends on chance. The probabilities involved depend on how many of each kind of molecule are present, the temperature, and so on. We have again loaded the dice to produce a desired effect.

We have not loaded the dice in the sense of cheating; we are not able to cheat nature. What we do in running a particular chemical reaction is to set up the physical conditions necessary for a large number of molecular reactions to occur within a short time. The higher the probability of the reaction, the more quickly and efficiently will our reaction run.

*

Now let us return to the chain reaction which was discussed earlier. High-speed, high-energy particles fly out of a disintegrating uranium nucleus. If one of these fragments strikes the nucleus of another uranium atom, the second nucleus splits, and more fragments are sent speeding away. In an ordinary piece of uranium ore, the probability is small that a particle will strike a nucleus. Since nearly all such particles fail to collide with a nucleus, no

chain reaction is started. However, if uranium is highly purified and an adequate amount of it is present, a chain reaction is started. A chain reaction results from our setting up the physical conditions in which the particles have a high probability of hitting a nucleus. Under such conditions, a chain reaction has a high probability. Once started, its probability gets higher and higher, and it will continue until all of the uranium is split. Because of the amount of energy released with each nuclear disintegration, an atomic bomb is possible. Thus, the chain reaction can also be accounted for on the basis of probability.

When we were busy popping corn, we found that the order in which the kernels popped, or the number popping per second was predictable only on the basis of probability. The bursting of each kernel was seen to be an independent, isolated event. We have also found that chemical reactions are best explained in terms of probabilities. Chemical reactions involve molecules colliding with each other, and collisions are chance occurrences. It follows, then, that the course of chemical events within a kernel of popcorn is also a series of independent chance happenings. It would appear that popcorn pops because it is placed in a situation (heat) which increases the probability of its popping within a given time.

In the last chapter it was pointed out that when we try to trace cause-and-effect relationships into individual molecules, we meet with failure. An attempt to observe (measure) what goes on among electrons and other atomic particles involves an inescapable uncertainty. This uncertainty is the result of the fact that the tools we use to make our observations tend to disturb the very relationships we are trying to measure. Such an inescapable uncertainty leads us to a different sort of an idea of probability than we have had in the past.

The old, classical idea of probability is much like the examples illustrated with dice. Probability was thought to be useful when cause and effect measurements were not practical. In playing cards, for instance, the probability of being dealt a bridge hand consisting of thirteen spades is very small indeed. However, if we examine the pack before it is dealt, the hand each player will receive is easily determined. The probability of being dealt thirteen spades is then either 1.0 or 0, depending on how we found the cards to be arranged in the shuffled pack: the hand is already determined, probability has nothing to do with it. The principle of uncertainty tells us that at the atomic and subatomic levels we cannot examine the pack before it is dealt. We must deal with probability only. It is as though we had tracked cause and effect relationships down through natural phenomena of all sorts, and when arriving at its very lair, the ultimate particles, we had found the door bolted from the inside.

We are now in the position of being forced to make a decision. One of the fundamental ideas on which science has been based is the infallibility of cause and effect. We now find that this idea cannot be tested in all cases. It is possible, of course, to assume that cause-and-effect relationships always hold, even though they cannot be measured. But this attitude becomes metaphysical, and not scientific. If we cannot test an idea experimentally, if we cannot measure it, it cannot be part of natural science. It can be only a way of thinking, not part of an objective body of knowledge. Thus, we have been forced to decide that cause-and-effect ideas are perhaps only a way of thinking. At the level of ordinary experience and nearly all scientific work, the concept of cause and effect is still useful, but we must remain in doubt about its ultimate infallibility.

Science started with the certainty of a determinate universe, with the idea of probability as man-made convenience. We have now reached the concept of a universe in which probability reigns, and the idea of cause and effect is a man-made convenience. With this idea we return to the quotation of Francis Bacon, with which the chapter began. 'If we begin with certainties, we shall end in doubts; but if we begin with doubts, and are patient in them, we shall end in certainties.'

7

THE SIMPLICITY OF SCIENCE

EXPLORERS standing on the shores of a strange continent look first for prominent features, landmarks which will guide them during more thorough explorations. On each side, from where they stand, the shore line sweeps away to where land, sea, and sky meet. Far inland, mountains are glimpsed, dimly shrouded by fog and distance. A trail, a pass, is to be found, that the land may be explored, mapped, and settled. Only then will its fertile valleys bear fruit, and its resources be harnessed. With such subjugation, the land loses its mystery and becomes a homeland: understood and familiar.

Up to this point in our exploration of the continent of science, we have considered only its major features. A great number of interesting aspects of science have had to be ignored. And a host of inviting philosophical byways have also been avoided. The goal has been simple – a description of the main characteristics of science. The most direct route possible has been taken to reach that goal. To digress would have been to expand this small book into a volume of encyclopedic size. Before pushing on to the effects of science on our way of looking at life, let us pause and look back over the trail we have travelled.

One by one, the major features of science have been examined and discussed. An attempt has been made to show how these characteristics are related, where they fit in simple relation to each other on the map of science. As with any body of knowledge, science can be no better than the methods used to obtain it. The scientific method con-

sists of observation, hypothesis, experiment, and interpretation. In this method lies the main strength of science, as it is a method for obtaining useful, tested, and refined information about the world. From experiments we went on to theories. Theories compounded from experimental observations serve to tie our knowledge together, that the world we know be one world. Theories, big theories and little theories, are derived from nature's facts by induction. Since facts and testing come before theories and laws, the face of science changes and, we are confident, improves as we gain more detailed and exact knowledge.

Perhaps it was a bit surprising to find that science is not based on observations and measurements alone. We found that even before such facts can be interpreted, there has to be a way of thinking about them. This way of thinking forms a set of assumptions or postulates on which the rest of our ideas may be based. We found that at least four assumptions lie at the base of science. These are very simple assumptions, but are also very far-reaching in their effects on our interpretation of nature.

The first of these assumptions, that nature is understandable, is also the simplest. This necessary assumption, however bold, is an essential part of every attempt to arrive at any sort of understanding. Our ideas of what constitutes an understanding have changed over the years. During the past half-century the idea of understanding in terms of mental models and strict causation has had to be abandoned to a large, disquieting degree.

The second assumption is one of unity. All of nature is subject to the same natural laws; all is part of one plan. This assumption is still largely untested, in an ultimate sense, but has proved to be of inestimable value in tying different phases of natural science together into a workable body of knowledge. In a later chapter we will examine

this assumption in more detail, as it relates to biological problems.

The third assumption is one of simplicity. It is that the simplest explanation consistent with pertinent observations is most probably correct. This is a sort of rule of thumb, and is very useful. It is quite untestable scientifically, however important it is to us from the standpoint of efficiency. This assumption has forced us to drop many subjective ideas from science.

We have dwelt at some length on the fourth assumption, that measurable causes underlie all observable phenomena. This idea of cause and effect has proved to be untestable in ultimate terms, and has been modified in recent years. We now think of cause and effect as a large statistically determined series.

With these details in mind, we can now define science in a short, formal sentence. *Science is a body of tested objective knowledge, obtained and unified in principle by inductive methods.* The previous six chapters are an explanation of this definition. Such a formal statement of the nature of science tells us nothing of the excitement and challenge of scientific research. Neither does it allow an appreciation of the peculiar limitations of science.

The boundaries of science are the boundaries of the material universe. Wherever physical forces and material bodies measurably interact, there is a subject for the methods and concepts of science.

A great deal of human thought and knowledge cannot, by its very nature, be included in the body of knowledge we call science. Scientific knowledge is efficient and broad in scope, but it is impersonal and does not, in itself, provide the answers to all the questions nagging at the mind of man.

The intellectual demands man makes of nature are not

concerned only with the physical structure of the universe. His ideological questions are centred in himself, in his own inquiring and aspiring mind. He is curious about problems of life and death, purpose, freedom, and whether he is alone in the universe. On these matters he builds his arts, his religions, and his philosophies. If science can help us to find answers to the questions we ask about ourselves and our lives, it will be from biology, not physics, that those answers will come. For biology is the science of living things, and the real riddles of the universe may not lie in an atom or in the far reaches of space, but in the throbbing of a living cell.

Let us, then, continue our exploration of science, and turn our attention to the science of the living.

8

THE LIVING WORLD

MAN stands in a world of life. All about him is a profusion of living things. In the soil at his feet there is life, myriads of microscopic plants and animals as well as the somewhat larger worms and insects. From the surface of the earth, wherever moist soil may be, plants reach toward the sun. On rocky cliffs where no soil can cling, the tenacious lichens spread. From the mountain tops to the deep valleys, life reigns gloriously over the earth. From the lower atmosphere into the far reaches of oceanic depths, life is to be seen and its call is to be heard. In the air, in the water, in the soil, on the rocks, and even on or in the bodies of other living things, there are creatures, each with a flame of life, and each striving for a place in the living world. Every kind of plant and animal is suited for its particular way of life, and it spends its brief span wresting an opportunity to live and to beget others of its kind. If it fails to meet this relentless challenge, it dies and disappears from the face of the earth. Its place, its niche in nature, is taken over by a more vigorous or adaptable creature, and this we call evolution.

Man is one of the most adaptable of all living things, an honour which he perhaps shares with his constant companions, the dog and the housefly. Man can maintain himself as a population high in the mountains, or in arctic wastes, or in tropical jungles, or in desert desolation. Individually, he has penetrated the depths of the ocean and the outer reaches of the atmosphere. Man is marvellously adaptable – except to man.

All of our accumulated knowledge of physical phenomena and the structure of matter will yield fruit as it leads to an understanding of the processes of life. For it is in his own living that man finds the questions that plague his mind and haunt his dreams. In the phenomenon of life seems to lie the potentiality of conquering the sterility of an unfeeling universe. Without the mysterious miracle of life, the universe would be a meaningless void. The key to purpose, value, meaning, and beauty must lie within the fact of the being of each living creature. Life is the centre of the universe.

In this age of science, we look expectantly to the scientific method and modern biology to find out what is known of the realms of the living world. The technical details of all that we know about organisms and organic functions would fill volumes and libraries of volumes. In this small book, it is not our purpose to wade through a great mass of technicality. What needs to be explored here is the scientific concepts of life and organism. We wish to know what science can tell us about the elusive thing called life, which seems to separate our world sharply into the living and the non-living. This exploration will lead us into many fields, and we will meet many provocative ideas. We will, indeed, experience something of the force of the terrific challenge which the living world presents to the mind of man.

Ordinarily, a person thinks of an organism as some sort of an individual creature – be it a man, bird, plant, or oyster. As an individual being, it is endowed with certain characteristics of form and behaviour which make it a particular species of creature. These characteristics it inherited from its ancestors, and it shares them with others of its kind. But in addition to such inherited properties, each organism has individual traits which set it apart

from all other living things. Anyone who has had a pet dog, cat, or even goldfish, easily recognizes the individuality of each creature. It is separated in time, space, and character from all others. In our every-day experience with the larger animals, such as dogs and horses, we tend to credit them with the emotions and mental processes of anger, love, hate, thought, freedom of choice, and so on. We tend to think of them as we think of ourselves – as individual beings, separate in spirit and creation from all other beings.

It is also generally recognized, of course, that an animal is dependent on its environment. It is adjusted in anatomy and behaviour for living under the conditions offered by particular surroundings. If we wish to catch a certain kind of animal, we must look for it in its usual haunts. Thus, one can expect to find mice in grassy fields, squirrels in trees, deer in forests. But the creature is not thought of as being part of its environment, nor is the environment thought of as part of the organism. In essence the two are separable, and although the large-mouth black bass lives in a lake, it can be removed from the lake and still be a large-mouth black bass.

What has just been described is a common-experience concept of an organism; that is, something distinct and individual, and endowed with the spirit of life. Biology started with such a general idea of living things, but in many respects this idea is very different from the picture obtained from modern biological science. Like the man who mounted his horse and rode off in all directions, we have departed from the naïve and common-sense view in many aspects. Biologists have used the methods and doctrines of science with vigour and persistence, to gain detailed knowledge of all types of living creatures and vital processes.

At the outset of a scientific study of life, a question arises as to how to approach the problem. This is not a simple question, and we still lack a satisfactory answer in many respects. In studying a living organism, we must disturb it to some degree. This disturbance is necessary in order to obtain any sort of experimental measurements. The disturbance may be slight or it may involve the death of the animal. In anatomical studies the animal is killed, and its dead form is studied. In most physiological and biochemical work, the organism is killed and the physical and chemical activities of particular tissues and organs are studied and analysed. Many organs will continue to function for at least a short time after the 'death' of the animal as a whole. For instance, the heart of a frog, turtle, or bird may be removed from the animal and will continue to beat for a time. If the proper conditions of moisture, temperature, and salt concentration are carefully maintained, the heart may function for many hours. Such an isolated heart is useful in the study of heart physiology and drug action, and for classroom demonstrations.

Another example of an aspect of an organism which will continue to function after the death of the organism is the action of enzymes. The cells and organs of a living thing contain an amazing array of chemicals. Some of the most complex of these chemicals are those which serve to control the speed of the chemical processes going on in the organs. These very complex and important substances are called enzymes. Biochemists have isolated and crystallized a number of enzymes from the cells and organs of plants and animals. As we delve farther and farther into the chemistry of living things, more and more enzymes are found. Only a few of the hundreds that are present have been studied to any extent. Even after years of being dry

crystals in a bottle on a shelf, many enzymes are still biologically functional when returned to the proper physiological environment.

Was the isolated heart living? Were the enzymes living? They were living to the extent that they were functional, but whether they were living in the same sense that an organism lives is an unanswerable question. The property of living is difficult to define, and the 'life' of an organism does not appear to be a fixed thing. The living process is far too complicated to be approached so rudely. A simpler and more objective line of attack is required.

We know from common experience that living organisms differ quite radically from non-living things. Then let us begin our inquiry by taking the fact of life for granted, and study the characteristics of things we call alive. This approach will allow us to progress in an understanding of organisms. Perhaps it will eventually lead to a meaningful knowledge of what might be called 'the essence of life'. This way of attacking the problem gives us a working concept of life as simply the properties of living things. As they are studied scientifically, and as we learn about how they function, we should acquire better and more efficient knowledge of the living world. However scientific and efficient and necessary this approach to the problem may be, it leads to knowledge only of 'organism'. It cannot lead us to a concept of 'life', except as displayed by organisms.

Such an arrangement may, at first, seem a little foolish: to define life only in terms of what life does, the characteristics displayed by organisms. With a moment's reflection, however, one will realize that this is precisely what must be done in all of science. What is known of objects and events must be based on what they do, how they behave. Since we know of these things only by obser-

vation and measurement, they can be defined only in that way. A photon, the physical unit of light energy, can be defined only in the terms of what photons do, the characteristics that photons display. The same has to be true of all nature – electrons and elephants, germs and sunspots.

The practical necessity of defining life in terms of living things, and all phenomena in the terms of related phenomena, represents one of the most serious limitations of scientific knowledge. But it provides a simple means of accumulating efficient knowledge. It defines the problem of life in terms with which we can work and which are consistent with the structure and assumptions of science. It involves no assumption that living creatures contain some immeasurable property or soul. Thus it does not help us to solve the problem of whether living things are fundamentally more than complex machines, a problem which will be explored in a later chapter.

Before studying living things for those characteristics essential to life, it is necessary to decide on some means of determining what should be called living and what non-living. This will give us a yardstick and a starting-point. In ordinary experience, living creatures are easily distinguished from the non-living. As a first rough measure of life, we may use some of these well-known characteristics. First, we know that living things can respond to different stimuli, such as light, touch, heat, and so on. Animals tend to react quickly, by twitching, moving, running. Plants usually respond slowly, as when a plant turns to follow the sun. In addition to the ability to respond to changing conditions, living creatures grow and reproduce. The young, the eggs, the seeds, the spores are to be seen everywhere. Plants and animals grow in size and in numbers. To respond, to grow, and to reproduce requires energy. Energy is needed to move, and to do work, and

to build bodies. Thus, the third general characteristic of an organism is that it is capable of metabolism. That is it possesses a means of obtaining energy from its surroundings. It is able to convert the chemical energy contained in foodstuff into energy for running, breathing, growing, and all of its other activities.

With these three attributes – response, reproduction, and metabolism – we have a means of making a distinction between the living and the non-living, at least grossly. An organism has another very important characteristic; it is a self-regulating body. The abilities to respond, grow, and reproduce, and metabolize are coordinated. All of the mechanisms and processes within the organism are knit into one system which functions to maintain the organism in a constant fully functional state. This is sometimes called the maintenance of a *steady state*. It involves both internal adjustments necessary to keeping the body functional and the ability to respond to the environment in order to maintain itself in favourable surroundings. The steady state tendency of an organism is quite essential to its survival, as it is the means by which the organism prevents disintegration by the environment.

There is still another important characteristic of living things. That attribute is the *capacity to evolve*. Plants and animals are not exactly like their parents. One generation is not a perfect copy of the preceding generation. There is a continual realignment of inherited characteristics. And abrupt changes occur too, which are called mutations. Through natural selection of individuals for fitness, this incessant shuffling of inheritance results in evolution toward populations that are more perfectly adapted to a particular way of life. The occurrence of mutations and the capacity to evolve has resulted in the vast multitude of living things found in nature.

There are well over a million and a half different kinds of creatures living on the earth. They range in size from giant sequoia trees to microscopic bacteria, from great blue whales to malaria germs and to the still smaller viruses. With such a multitude of forms and shapes and kinds of organisms with which to work, we would be defeated by confusion unless we had some system for identifying them. Devising a scheme which would be both convenient and workable as a means of classifying and identifying all of these organisms was a big problem. A satisfactory system was not hit upon until the middle of the eighteenth century. A Swedish biologist by the name of Carl von Linné (Linnaeus) devised the system which is still in use. And the life works of many biologists of the past and present have been devoted entirely to identifying, naming, and classifying plants and animals. This branch of biology is sometimes called *taxonomy*, although the modern word *systematics* is a better description of what these biologists do.

Living things are divided into two biological kingdoms: the plant kingdom and the animal kingdom. The division is possible in all but a few cases, for there are a number of very small organisms which show the characteristics of both plants and animals. They are intermediates, and indicate that plants and animals probably had similar beginnings. With the plant and animal kingdoms, the first big categories are called *phyla*. Animals are divided into phyla according to their gross bodily form and organization. Thus, all one-celled animals are in the phylum Protozoa. The jellyfish and all of its relatives are in another phylum; the octopus and oyster in another; insects, spiders, and lobsters in still another; and so on. There are about two dozen of these major categories called phyla. Within one phylum, the range of forms is still very large.

The phylum Chordata, for instance, includes all of the animals with backbones – sharks, turtles, birds, and man. The phyla are subdivided into classes. Within the phylum Chordata, the fish are put into one class, toads and frogs in another, birds in another, and so on. Man and all the other mammals are in the class Mammalia. The classes are further subdivided into orders; orders into families; families into genera; and genera into species.

This system of classification serves two purposes. One purpose is simple convenience. Each plant and each animal known to man is assigned a name. Its scientific name identifies it the world over. The other purpose for the classification system is to show how different species are thought to be related to each other. The aim of systematics is to arrange all the animals and plants into a big family tree. Systematics is concerned with the genealogy as well as the cataloguing of life on earth.

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The idea of one classification scheme, showing how different living things are related to one another, is an indication that we think there is a unity among different forms of life. This is a major biological principle. It is a principle of such scope and importance that it is the bedrock on which other biological theories are built.

The whole concept of evolution rests on the idea that the great multiplicity of life on earth today evolved from fewer, simpler forms which lived hundreds of millions of years ago. Evolution by natural selection or by any other means involves accepting the idea that different plant species and different animal species are at least distantly related to each other. The principle of biogenesis, it will be recalled from an earlier chapter, states that all life

came from pre-existing life. This means that life has been a continuing thing, down through the ages. Its spread over the earth and its great diversification must have been by multiplication and adaptation.

A belief in a fundamental similarity of all living organisms lies at the base of most pharmacological and physiological research. When drugs and poisons are tested on rats as a means of getting an idea of their probable effects on human beings, the assumption must be made that in some way a rat is similar to a human. Serums and vaccines are used to protect men, women, and children against diseases. These protective substances may be obtained through the use of eggs, rabbits, horses, and monkeys. The antibodies formed by these animals give the human body a boost in forming its own antibodies. The general defensive methods in eggs, rabbits, horses, and monkeys must be basically similar to those found in man. For were it not so, such methods of production and experimentation would not work.

A great body of scientific information has been gathered on the subject of nutrition. The application of this knowledge to human dietary problems has greatly improved the health and well-being of the last two or three generations. The experiments that yielded this knowledge were not conducted on people; they were run on animals – chickens, rats, guinea-pigs, and dogs. And what was found out about the nutritional needs of these animals was usually found to be meaningful to human diets as well.

All animal organisms are faced with the same problem of maintaining an organized and fully functional body. Certain organic functions appear to be required for the maintenance of an organism, regardless of its particular way of life. Every animal must have a way of obtaining

food, and then a way of digesting and utilizing it. It must have some system worked out for getting rid of its wastes. It must also be the possessor of a coordinating system and a means of reproduction; and so on.

The structure or anatomy by which these requirements are met may differ from one species to another. But every organism must have some means of accomplishing them. Even though the organization of widely different animals may be dissimilar, each of these functions must be efficient enough to enable the species to survive, generation after generation. In a one-celled animal the requirements may be simplified, but the general requirements are the same. If we are justified in saying that there is unity among organisms, that they are fundamentally similar in their operating processes, there should be pronounced similarities in the functional details of their organ systems.

Let us explore this idea by comparing two animal forms that are quite different in anatomy, classification, and way of life. For this purpose we will compare a mammal with an insect; more specifically, a dog with a cockroach. Both are highly successful animals. Neither is over-specialized in its way of life, and both are world-wide in distribution. The dog is an animal which has an internal skeleton, a backbone, and a spinal nerve cord. These characteristics make the dog a member of the phylum Chordata. The cockroach, on the other hand, has its nerve cord running along its belly side, a shell-like external skeleton, and jointed appendages. By these characteristics, the cockroach is consigned to the phylum Anthropoda. The dog has fur, warm blood, and it suckles its young; it is of the class Mammalia. The cockroach's six legs and pair of feelers put it in the class Insecta. It is hardly necessary to point out all of the anatomical differences between the dog and the cockroach. Of more interest to us here

are differences and similarities in the form and functioning of some of their vital organ systems.

METABOLISM

The respiratory system of the dog is like that of other mammals. It breathes air into its lungs, and the oxygen contained in the inhaled air is absorbed. It is absorbed by the red pigment of the blood. The circulatory system, consisting of heart, arteries, capillaries, and veins, distributes the oxygen-carrying blood to all parts of the body. Carbon dioxide, a respiratory waste product, is carried by the blood from all parts of the body, back to the lungs, where it is exhaled. The cockroach, like other insects, has a quite different respiratory system. It has no lungs, and the blood stream does not carry either oxygen or carbon dioxide. Instead, the cockroach is equipped with a network of hollow tubes which ramify into all parts of the insect's body. The system of hollow tubes opens to the outside air at a series of porthole-like openings along each side of the body. Oxygen and carbon dioxide ooze in and out via the side openings, being aided somewhat by the walking, running, and other movements of the cockroach. Such a ventilating system works quite well for a small creature, but would not be efficient enough to meet the needs of an animal the size of a dog.

Any animal organism, no matter how large or how small, must have some means of obtaining oxygen. The smaller the animal, the simpler the respiratory system may be. Mammals have a very efficient system of respiration, by virtue of their complicated spongy lungs and highly developed blood system. The gills of a fish are another way of doing the same job, but in an entirely different environment. In the insects, the tracheal system, the network of hollow air tubes, serves the same purpose. To be

sure, the tracheal system is not so efficient as the lung system or even the gills of a fish. And their respiratory system relegates the insects to be perpetual members of the category of small animals. Lungs, gills, tracheal tubes – the job they do is the same in each case, to deliver the oxygen required to keep the cells and tissues alive. The differences between the respiratory systems of dog and cockroach appear to be mere technicalities of structure.

Both the dog and the cockroach require a means of exchanging oxygen and carbon dioxide between their bodies and the atmosphere. It might be suspected, therefore, that the use that they make of oxygen within their bodies are also similar. The process by which an animal uses oxygen is called *respiratory metabolism*. It may also be called energetic metabolism, for it is the means by which the organism obtains the energy it needs to carry out its activities. The energy is derived from food materials consumed by the animal by a process of oxidation; that is, it uses oxygen. Oxidation is an energy-producing chemical reaction. A fire is the simplest example of oxidation, and the energy produced is given off as heat. If a lighted candle is placed in a stoppered bottle, the flame dies out as it uses up the oxygen in its small supply of air. So it is too with an animal. The respiratory metabolism in an animal is neither as simple nor as crude as a candle flame. But it is similarly an energy-producing oxidation. Respiratory metabolism is an exceedingly complex process, and although it has been studied and investigated very intensively, we still have much to learn of it. Out of the hundreds of thousands of research hours that have been poured into the subject, a concept of metabolism has been developed which is a triumph of scientific thought.

The story of respiratory metabolism necessarily begins with the food required by the animal. For in the dietary

needs, we find a clue to the raw materials needed to keep the metabolic fires burning. To return to our comparison of the dog and cockroach, the similarity of their dietary requirements is really quite striking. The dog is normally a carnivorous animal, a meat eater. The cockroach is a general feeder; it will eat a wide variety of plant and animal material. But this difference is actually very slight; when put on experimental diets, their basic requirements for energy foods (carbohydrates and fats) and body-building proteins are about the same. Even their digestive processes are similar. This equality of dietary needs is by no means peculiar to the dog and cockroach. It has been found to be the case with every animal species studied. Small differences in food requirements have been found among different animals, but they seem to be minor specialized requirements.

Modern nutrition studies have placed great emphasis on vitamins. The detailed vitamin requirements of quite a number of different types of animals have been studied intensively. Knowledge of the vitamin needs of some animal groups is still meagre, but enough have been studied to enable us to detect a general pattern. The vitamin requirements of mammals, birds, and insects are better understood than those of other kinds of animals. It has become quite apparent that they all require essentially the same array of vitamins. The vitamin needs of the dog and cockroach are quite similar.

There are eleven known vitamins of the B complex. Five of them are required in the diets of all animals studied. Of the other six, some will be required in the diet of one animal but not in the diet of another kind of animal. Sometimes the micro-organisms living in the intestines of an animal will manufacture some of the vitamins, and the animal will get them that way. It has been

found that a few animals can manufacture one or two of the vitamins themselves. But by one means or another, at least ten of the eleven B vitamins must be available to the animal's body tissues and organs. Insects, birds, mammals, fish, snails, or what have you, all require these same B vitamins.

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The similarities in the nutritional needs of dogs and cockroaches and all other animals as well, tend to support the idea that all forms of life share many characteristics. The need of all animals for the B vitamins indicates that these particular chemicals must play a very important role in maintaining life. And in the universal requirement for the eleven B vitamins there may be a bond of equality which unites all forms of life on earth. If we can determine the exact function of the vitamins in the vital machinery of the organism, we may be able to discover much about the elusive processes of life and to improve our scientific concept of what is an organism. So let us follow this line of exploration a little farther, for it will lead us back to respiratory metabolism and will allow us to form a reasonably coherent picture of how animals obtain and use energy to meet the challenge of staying alive.

Research work on vitamins began in earnest between 1910 and 1920. The first one studied was thought to be an amine, which is a particular class of chemicals. It was also thought to be quite essential to life. For these reasons, it was called a *vital amine*, and this idea gave rise to the term *vitamine*. In more recent years it has been shortened to *vitamin*. Since that time, vitamin research has been intensive and successful. Biologists and biochemists soon began to realize, however, that they were on the verge of

discovering something tremendously important to both human knowledge and human welfare. Even in the excitement of the early discoveries, it was realized that vitamins are not like other foods. They are required in the diet in only very small amounts. The amounts needed are far too minute to allow anyone to think that they might be broken down and digested like other food. They appeared to be key substances of some sort, even though their number and universal importance were not suspected by the early workers. What was not understood was just how and where the vitamins fitted into the make-up of an animal. Then new light was thrown on the problem by discoveries made through research on respiratory metabolism.

Biologists and chemists working on respiratory metabolism had, for some time, recognized that the metabolic processes are promoted and controlled by enzymes. Enzymes are very large and complex protein molecules that are found only in living things. They have very specialized functions, and are quite essential to the life of an organism. They make it possible for certain chemical reactions to occur quickly and at a controlled rate. Without the enzymes these chemical processes would take place far too slowly to maintain life. Plant and animal cells seem to be full of different enzymes, each with a specific chemical chore to do. The life of an organism is dependent on the continuous and coordinated workings of its multitude of enzymes. Research workers studying the nature and functions of enzymes discovered that many of them are actually more than just a big protein. They found that in addition to the giant protein molecule, a small molecule was attached to it. It was also found that the little molecule was just as important as the big protein body, as far as the actual working of the enzyme was

concerned. This small part was called a *coenzyme*. The coenzymes turned out to be different sorts of chemicals in different cases, depending on the type of enzyme. Most pertinent to our story is the fact that coenzymes were found to play a very important part in respiratory metabolism.

After a period of difficult and sometimes very confusing research on coenzymes, one of them was finally identified as a chemical called riboflavin. And with this discovery, we return to the story of vitamins, for riboflavin is none other than vitamin B_2. Riboflavin was identified as a coenzyme in 1934, and within three years vitamin B_1 and niacin (another B vitamin) were also found to function as coenzymes in respiratory metabolism. Since that time, it has been found that the other B vitamins also fit into respiratory metabolism as coenzymes. They have been found to have the same specific functions in every living thing studied, plant or animal, dog or cockroach.

What has been learned about respiratory metabolism is far too complex to be discussed here in any detail. It is, of course, the series of chemical processes by which the cells and tissues convert the energy in food to energy forms needed for muscular work and all of the other activities of the animal. We do not yet know nearly all there is to be known of these processes. But it has become quite apparent that they are fundamentally similar in all organisms. The similarity in vitamin requirements and vitamin function among widely different animals is but one example. Many others have been found as well.

Our exploration of biology, and our quest for a concept of what makes up an organism, has led to one item of understanding. We have found one bond of unity that runs through the living world. We have seen that the different forms of animal life have the same sort of re-

quirements for oxygen, food, and vitamins. They utilize these things in the same ways, to obtain the energy needed for carrying out activities and to maintain themselves on the face of the earth. Respiratory metabolism might be called a chemical engine, using food as fuel and providing the energy to drive the machinery of the organism. Around that metabolic engine is built an organism. But the organism as a whole is certainly more than just its metabolism. We can make many of the chemical reactions of metabolism work in a test tube, but we do not think that we have created an organism. The differences between a man, dog, and insect must be sought in some way other than through studying the details of respiration, diet, and metabolism.

COORDINATED RESPONSE

Metabolism was but one of the characteristics by which we separated the living from the non-living at the beginning of this chapter. Two other properties of organism were also used. They were response and reproduction. Thus let us next turn our attention to the organism's ability to respond. Response, if it is to lead to effective reaction or adjustment, must involve a certain amount of coordination. At least two types of coordination are necessary to the life and activity of an animal. One kind of coordination is internal. The functioning of the different organ systems must be coordinated so that the animal can maintain itself as a unit. And it must be in an internal state of readiness to react purposefully to what goes on in its outside world. This leads us to the external type of coordination, that between the animal and its environment. The organism must have a means of detecting and reacting to the great variety of sights, sounds, smells, tastes, and touches which come to it. These two coordin-

ating activities are carried on by two closely cooperating organ systems. The integration of the internal affairs is accomplished chiefly by the *endocrine* (hormonal) organ system. The ability of the organism to react to things in its external environment is controlled by the *nervous* system.

The nervous system is the most complicated of all the organ systems, and it is the most mysterious and difficult to study. In its complex labyrinths may lie the answers to our questions as to the nature of mind, consciousness, intelligence, and instinct. There is quiet confidence among most biologists that all behaviour will ultimately be explicable in terms of the activities of the animal's nervous system. The differences between man and other creatures is thought to lie in the fantastic development of man's brain, the centre of his nervous system.

Nerves are delicate fibres woven into a far-reaching system by which every part of the body is connected to every other part. Nerve cells are highly specialized in structure and function. They are specialized for transmitting signals from the sense organs to the brain and from the brain to muscles and other organs. The routing and use of these signals – or more technically, *impulses* – form the basis of the animal's ability to react. The nerve impulse is, in itself, a very interesting phenomenon. It is a complex chemical change that sweeps like a ripple along the nerve. Its movement and course may be followed with suitable recording instruments, and it acts like an electric signal.

An example of a simple stimulus and its consequences may be illustrated with a pin. Suppose that we use a pin to prick the skin of a dog. The dog will react to this stimulus, of course. The entry of the pin into the skin causes a disturbance in the sense organs located there.

This disturbance gives rise to a chemical and electrical change in the sense organs. The electrochemical change starts in a sense organ and then moves through the nerve toward the rest of the dog's body. It travels along the nerves like a wave, and we now call it an impulse. When the impulse travels along a nerve leading to a muscle, it will cause the muscle to go into action.

If the nervous system of the dog were nothing more than a network of nerve fibres permeating the whole body, the pinprick would result in a spreading impulse. As the impulse swept over the nerve network, all muscles would contract, the whole body would respond. This is precisely what happens in a lowly creature, such as a jellyfish. The jellyfish has a nervous system which is simply a net of nerves. Of course, the dog does not react in this manner; it may display any of a number of reactions. It may flinch, yelp, snarl, bite, run, or show any combination of such doggish behaviour.

The behaviour of the dog is more complex than that of the jellyfish, because its nervous system is more complex and is more highly organized. Instead of a simple network, the nervous system is arranged so that impulses may be sorted out and then directed to selected parts of the body. The brain and spinal cord function in this sorting and directing, and they make up what is called the *central nervous system*. Nerves from the sense organs deliver their impulses into the central nervous system, the spinal cord for instance. Within the spinal cord, the impulse is passed to other specialized nerve cells. These cells pass the impulse on to the brain and also to other nerve pathways. In the brain, the impulse may also be shunted into various channels. We are still abysmally ignorant concerning just how all of this sorting and directing of impulses is accomplished. But if scientific research can find the key to an

understanding of animal behaviour, that key probably lies in this process. The apparent readiness with which an impulse is shunted into a particular nerve pathway depends on the experience, training, and instincts of the animal. Instincts seem to be particular inherited nerve pathways.

To return to the dog which we insulted with a pin, the first thing that we will observe is that the dog will flinch or jump slightly. This is a reflex action. That is, the nerve impulse travelled from the skin to the spinal cord, and from there directly to muscles, without any complicating signals from the brain. Anyone who has unknowingly touched a hot object has experienced a simple spinal reflex. The touching hand jerked away from the hot object instantly. The motion was automatic, and required no thought or decision. But the object also felt hot; so an impulse must also have been sent to the brain. Thus it was with the dog; the flinching was a reflex response to a small annoyance. Following this, the dog might merely glance around to inspect the source of irritation. Such an action would be caused by impulses from the brain. What further response the dog makes will depend on the idiosyncrasies and past history of the particular dog involved. A timorous dog might try to run away; a vicious dog might bite the hand wielding the pin. The pinprick, in these cases, is no longer an isolated thing, but has set into operation a large complex behaviour pattern. And the factors contributing to this pattern come from the entire past history of the dog, not just from the moment at hand.

A dog can be trained to respond to a pinprick in just about any way we wish it to. Suppose that we prick the dog on a leg and then immediately offer it food. This performance is then repeated every day, day after day. The dog is never stuck with a pin except just before it is

fed, and the dog is never fed without first being stuck. Before this ritual has been repeated very many times, we will observe a surprising change in the dog's reactions. Instead of showing a mild pain reaction upon the pinprick, it will display unmistakable signs of food anticipation. It will salivate, lick its chops, and anxiously await the appearance of the food it has learned to expect. The dog's reflex action toward the pinprick has been changed, or conditioned, by its experience. It no longer means a pain, but it means 'meat on the table'. The response of the dog is now called a *conditioned reflex.*

With the dog, we deliberately created a conditioned reflex, but it may be by this general method that animals learn under more natural condition. When I was a second-year student at college, I had a job in the zoology department. Among other chores, I took care of maintaining a supply of minnows to be used in experiments. The little fish were kept in small aquaria, which were covered with pieces of plate-glass. Feeding them involved removing the glass plates and sprinkling dried fish-blood on the water. When a fresh group of minnows was placed in a tank, they were easily frightened, and removing the glass plate threw them into something of a frenzy. After a week or two, this behaviour changed entirely. When the glass plate was moved, the fish immediately came to the surface and began what appeared to be a search for food. The rattling of the glass plate no longer was something to be feared; it had come to be associated with food. The story is one of conditioned reflexes. It has become quite apparent that the conditioned reflex is of great importance in animal learning, but much behaviour is too complex to be accounted for on this basis alone.

The nervous system of a mammal is vastly more complex than that of a lower animal, such as an insect. In the

insect, there is less nerve tissue, fewer possibilities for complex nerve pathways. Its behaviour, then, is simpler and more completely explicable in terms of reflex actions. The differences between the nervous systems of the dog and cockroach appear to be differences in degree rather than in kind, however. The nerves of the insect are similar in structure and in functional detail to those found in the mammals. As in the higher animals, the nervous system of the cockroach is organized into a central nervous system consisting of brain and nerve cord. From this central system nerves lead out into the different parts of the body. The brain of an insect is simpler than that of a mammal, and it probably plays a smaller role in behaviour. But it serves the same general function as a sorting and directing centre. The anatomical structure of the individual nerves of an insect is almost identical to the nerve structure in the mammal. The biochemical details of the manner in which nerves function in insects are nearly indistinguishable from those found in mammals and man.

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As mentioned earlier, there is a second organ system involved in the integration and coordination of the body. It is the endocrine system. Endocrine glands secrete hormones. The thyroid and adrenal glands are two of the endocrine organs found in man and the other mammals. The hormones they secrete are thyroxine and adrenaline. Hormones have been called 'chemical messengers'. They have been so dubbed because they are carried by the blood stream to different parts of the body, where they have considerable effects on the functioning of other organs. Thus, the endocrine glands influence the activity of other parts and organs, not by direct contact as with the nerves,

but by secreting controlling chemicals into the blood. The study of hormones and their effects is an important and vigorous branch of physiology known as *endocrinology*. Great strides have been made in this field, but as knowledge of hormones increases, it is more and more obvious that what has been discovered thus far is merely a good beginning. The secretion and action of a great multitude of different hormones are probably necessary to the amazing internal organization of an animal. There seems to be a fascinating system of hormonal checks and balances in operation to keep the body functioning and in a steady state.

In man and the vertebrate animals, one endocrine gland is considered the 'master gland'. More technically, the master gland is known as the pituitary. It is a small glandular body lying between the roof of the mouth and the brain. Part of it is actually made up of brain tissue; so the pituitary is very closely connected to the nervous system as well as being a glandular organ. The pituitary manufactures and releases a whole host of different hormones. Pituitary hormones control the growth and reproduction of the animal, and they also control the functioning of many of the other endocrine organs, such as the adrenal glands, thyroid, ovaries, testes, pancreas, and so on.

How are the hormones involved in an animal's ability to respond to things and forces in its environment? 'In the spring, a young man's fancy lightly turns to thoughts of love.' Besides that sort of thing, there may be other situations that arise and require fast action. Perhaps you are strolling along a country lane on a lazy summer afternoon. The sun is warm, and the scenery pleasant. In a field just off the lane, you spy a shady spot by a brook. Climbing over the fence, you amble over to the shade,

thinking of how restful it will be to lie on the grass, and relax, and watch small fluffy clouds march slowly through the blue sky. You are just about to settle down when a rapid thumping penetrates your peaceful consciousness. Idly turning to see what is causing the noise, you are horrified to see a huge black bull bearing down on you at full speed. This bull has no appreciation of idyllic beauty. Nor does he know that you have a certain importance as a member of the famous human race. Something must be done, and done quickly. Not wishing to become a bullfighter, you will probably choose to run. Running faster than you had ever before, you make it to the fence and are over it in one leap. There was no time to think, no opportunity to map strategy; the situation called for violent and immediate action. Only after you were safely on the other side of the fence did you stop to think. And you wondered how you moved so swiftly and jumped so well. The answer is adrenaline, the 'fight or flight' hormone. The sight of the charging bull was, of course, received by the eyes, interpreted by the brain. Alarms from the brain caused the release of quantities of adrenaline. Adrenaline strongly stimulates metabolism, and provided the supercharge of energy needed to escape the bull and clear the fence. After reaching safety, your knees shook and your brow sweat, while the hormonal balance of your body returned to normal. Without that extra boost of adrenaline, you might have ended as a bloody spot on the grass.

Enough is known of the endocrine systems of the lower animals to justify the statement that the internal processes of animals in general are controlled and coordinated by hormones. Of the lower groups, the insects have been studied more than the others. Although the chemical structure of their hormones is different, the endocrine

system of an insect appears to be as important and as well-integrated as in a mammal. Insects do not have a pituitary gland, but they do have a 'master gland'. Surprisingly enough, the master gland of the insect is associated with the brain, and it is made up partly of brain cells, just as with the pituitary gland of higher animals. As biology advances and as more intricate problems are brought under the analytical scrutiny of the scientific method, more evidence is found of a bond of unity among all forms of life.

GROWTH AND REPRODUCTION

The third characteristic of an organism, as we defined it, is its ability to grow and reproduce. Growth and reproduction involve the multiplication of cells. They also involve specialization of cells in forming different tissues and organs. Before we can go into even a sketchy survey of these complex subjects, we must take a look at cells to see what they are, and why they are important biologically.

Organisms are made of matter, living matter called protoplasm. Protoplasm is a watery mixture of proteins, fats, and other complex organic chemicals. The protoplasm making up an organism is divided into well-defined little units called cells. Out of these tiny living bricks, the bodies of plants and animals are built. The tiniest animals (protozoa) and the smallest plants (bacteria and algae) are creatures whose microscopic bodies consist of but a single unit, a single cell. Plants, from a towering Douglas fir tree down to green pond scum, and animals from a huge elephant to a tiny mite, all show this one great similarity: they are made of cells. The unit of the organism is the cell.

A cell is a globule of protoplasm, but it is really a great deal more than just that. It is a highly organized exquisite

bit of living stuff. An animal cell examined under a microscope is seen to be a jellylike thing, but with some degree of organization faintly visible. First, the outer surface of the cell is visible as a thin membrane. Every substance that enters or leaves the cell must pass through that membrane. The cell membrane is not merely an inert barrier, but is actively involved in maintaining the cell in its environment. Below or inside the membrane lies the second part of the cell, the cytoplasm. The cytoplasm is the watery substance which forms the bulk of the cell. Here much of the work of the cell is carried on. Bundles of enzymes keep the metabolism operating, and within the cytoplasm are the raw materials and end products of the cell's activity. The nucleus is the third principal structure of the cell. The nucleus is generally a small spherical body which is found in the middle of the cytoplasm. This is the functional centre of the cell. In some way yet to be discovered, the nucleus controls and regulates the activity of the whole cell.

The cell nucleus is a mysterious and challenging entity. Though we suspect that it holds the answers to many of our questions about life processes, we are still woefully ignorant about much that goes on in that tiny structure. It is well known that the nucleus is involved in the reproduction of the cell; that is, it controls the dividing of the cell into two parts to form two separate cells. From our standpoint, the most important role of the nucleus is the part it plays in heredity. Within the nucleus there are a number of tiny complex fibres called chromosomes. Within these fibres there are thousands of entities called genes. We know of the genes mainly by the effects they have on the cell and the whole organism. Just what the gene really is, is still poorly understood, although we are pretty sure that it is a particular type of chemical complex. Of course,

every physical thing in the world is made of chemicals of one kind or another. But what is so astounding about genes is that they are complexes of only four different, but closely related, chemicals. We know that genes control the form, behaviour, and functioning of an animal, and that thousands of characteristics and processes are directly controlled by them. Yet, only four chemicals are involved – the same four in every gene. It seems, then, that the action of a gene is dependent on the way that these chemicals are linked into complexes and chains; in other words, on their patterns.

Genes are of utmost importance from a biological standpoint. They are the means by which heredity occurs. A child does not inherit brown eyes, curly hair, and a long nose from his parents; he inherits only genes. Some of the genes he inherits may bring about the development of brown eyes, curly hair, and a long nose. The genes are the materials actually passed from generation to generation. Each plant, each animal, each person starts life with this legacy out of the past, from the beginning of life on earth.

This general picture applies to cells wherever we find them. Plant cells or animal cells, they display the same sort of organization and functions. This is yet another powerful reason for interpreting the phenomena of life as having an underlying unity.

There are many kinds of cells, however: muscle cells, nerve cells, gland cells, leaf cells, and root cells, to mention but a few. All of these cells differ in the type of structure and function which they have developed. Muscle cells are long cells specialized in such a way that they contract when they are stimulated. Bone cells are differently specialized; their metabolism produces the hard substance of bone. Nerve cells are long and fibrelike and

are very sensitive. And so on. We do not yet know just how cells become specialized so that groups of them develop into different kinds of tissues and organs. Much research has gone into this intriguing mystery, and in time the answers to our questions will be found.

Let us start at the beginning of the formation of an organism. We will start with a fertilized egg-cell of a monkey. Within the tiny (about $\frac{1}{100}$th inch) spherical cell is a nucleus. Within the nucleus is a set of genes, half of which came from the male parent and half from the female. The genes are the egg's inheritance from the being and ancestry of the two parents. The fertilized egg is, in itself, an organism of sorts; a one-celled organism. But it does not possess the genes necessary to continued existence as a simple, single cell. If it is the egg-cell of a monkey, it possesses the genes of a monkey, and it represents a potential monkey. It will develop and realize that potential by the expressed activity of becoming a monkey. The potential is within the nucleus, where the genes constitute a monkey blueprint.

The first step toward developing into a complex organism is simply to increase the number of cells present. The egg-cell divides into two. Each gene also reproduces itself, so that when the cell divides to become two cells, each of those cells is equipped with a full set of genes. Now instead of one egg-cell, there are two, identical in appearance, structure, and potentiality. If they are separated by accident or experiment, each will proceed to develop into a separate monkey. When this happens, identical twins are produced. But if, as is normal, the two cells are touching, they will both contribute to the development of but one monkey. The two cells then divide again to form four cells, then eight, sixteen, thirty-two, and so on. If this went on indefinitely, a big mass of

identical cells would result, and no monkey would ever be produced. But this does not happen. After a hundred or so cells have been formed, an amazing thing begins to take place. The cells begin to specialize and to form the beginnings of the organ systems. This spectacular process may be watched in a bird's egg, simply by cutting a window in the shell over the embryo. One may then observe the miracle of life creating a bird. One may watch the appearance of the beginning of the vertebral column, the laying down of the outline of the brain-to-be. Before one's eyes, the heart takes shape and begins its lifelong task of throbbing. The main blood vessels may be seen forming and becoming connected to the beating heart. One can see the eye taking shape, muscle tissue forming, and the development of the digestive tract. And although we can observe and describe what we see, observation and description do not constitute understanding. We must probe with experimentation if we would have deeper knowledge.

Many interesting and illuminating experiments have been run on developing embryos. We now know that in the very early development, their cells are unspecialized. Whether a given cell will develop into a nerve-cell or a skin-cell depends on its position in the animal-to-be. Later it loses much of its versatility, and if it started to become a nerve, it will become one regardless of where we might transplant it in the embryo. There is still so much to be learned about cell growth and specialization that one is hesitant to say that we now know anything about it. It is suspected that genes – the units of heredity – are involved, because so many minor characteristics are determined genetically. Certainly an organism inherits its species membership from its parents; so genes must be involved. This leads us to the point of view that the form, size,

organic make-up are all determined by the genes present in the fertilized egg-cell.

Superficially, all mammalian fertilized egg-cells look pretty much alike. Yet, if allowed to develop unmolested and in its natural habitat, one will give rise to an elephant, one to a rat, and one to a man. The potential to develop into elephant, rat, or man must lie in the genes. These three forms of life must have a lot of genes in common – all those leading to the characteristics of mammals. Superimposed on those held in common are those for elephantness, ratness, or manness. And superimposed on those genes must be the genes which distinguish the individual from others of his species. These last genes are the ones with which the geneticist has worked the most, and they may be the least important of the lot. Although we have yet to find a way to experiment with the genes controlling really fundamental characteristics, we have no reason to doubt that they are genetically determined. Among the lower animals the genes are different (the same four chemicals, but different complexes). The mechanisms of inheritance and growth, however, are the same as in man and the higher animals. One of the favourite experimental animals of the geneticist is the fruitfly, a tiny insect. The laws of inheritance found in the fruitfly are applicable to breeding cows, dogs, race horses, or marigolds.

In this short and incomplete exploration of biology, an attempt has been made to develop a concept of an organism. Starting with three obvious properties of living things – response, metabolism, and reproduction – it was seen that widely different kinds of organisms are surprisingly similar in the manner in which these functions are carried out. Although animals differ in the anatomy and complexity of their organ systems, such differences seem to have developed from fundamental similarities. Scien-

tific clues to fundamental differences appear to be in the genes, for it is by genes that a creature inherits its particular membership in the living world. The biological potential of an organism, be it a man, mouse, or mosquito, is to be found in its allotment of genes. But this does not mean that a man is no more than an insect that made good, differing only in the identity of his genes and the complexity of his organs. In biology we deal with the material mechanisms of living things. We seek to understand the means by which organisms make their way in the world. This leads to a concept of what constitutes an organism, how it is put together, how its machinery works, and how it manages to hold its place on the face of the earth. Whether life is something more than these mechanisms, and what purpose is to be found in the life of man or animal are problems which demand that we probe deeper.

9

ONE WORLD?

On the campus of a large university, two scientists are studying two series of photographs. One of the men is a physicist, and he is studying a film record of the behaviour of subatomic particles hurtling through a Wilson cloud chamber. Across the campus, far from the Department of Physics, the second specialist is in his laboratory in the Department of Biology. The photographs being scrutinized by the biologist are a time-lapse film of a group of insects. He is studying the behaviour of these little animals in regard to how they feed and how different experimental conditions influence their feeding behaviour.

No one doubts that the particles receiving the attention of the physicist are quite different from the animals studied by the biologist. The difference which is most obvious is that the physicist's particle is relatively simple; whereas the animal is an exceedingly complex organized system, probably composed of the 'physicist's particles'. But if the biologist should assert that living creatures are more than just highly organized matter-energy, and if he should claim that there are manifestations of life far beyond what can be accounted for by physical concepts, he may touch off quite an argument. Whereupon we come face to face with one of the most important, most ancient, and most intangible of all science-philosophy problems. Is the world of biology separate, in any degree, from the world of physics? Or is biology destined to become no more than a study of very complex physical problems? In its phenomenal growth and success, physics has engulfed

much of natural science. Many aspects of biology have been accounted for in terms of the concepts developed in the science of physics. This is no superficial problem. It is of great importance to the development of the biological sciences, and to the relevance of science to philosophy, and to the interpretation of the universe from a human point of view.

One of the first questions that clamours for an answer has to do with how well we can separate the living from the non-living. It must be realized, of course, that scientific study of living forms is limited to measurements and manipulations of those aspects of life which involve matter and energy, space and time. But even with this limitation, we should be able to learn whether living things are sharply divided from things not ordinarily thought to be living. A simple approach to this problem would be to determine how successfully we may distinguish an organism from its environment. The idea of an organism separated from any sort of physical surroundings is an abstract idea. An organism without an environment is a physical impossibility. We have learned by simple observation, and by experiment, that different species of creatures are adapted to different kinds of situations. A plant or animal will soon perish in alien surroundings, and we say that it dies because it is not adapted to the strange environment. An alligator will die if transported to a desert. It dies because it is unable to adjust to a desert way of life. Alligators are adjusted in anatomy, physiology, and behaviour to the environment of a tropical swamp. The alligator's adaptation to such swampy environments seems to be an integral part of the very being of an alligator.

But does such adaptation make the environment part of the organism? From a number of standpoints it does,

and in some ways an organism can be only vaguely distinguished from its environment. This point may seem quite absurd. It might be argued that only the animal's adaptive, specialized features can be related to the environment, and that the fundamental, actual organism must be distinctly separate from the non-living world which surrounds it. From a scientific standpoint, however, the problem does not seem to be quite that simple, and separating organism from environment becomes more and more difficult as smaller and simpler forms of life are considered. This point may be made clear by considering the case of a single-celled animal.

A little one-celled animal called an *amoeba* lives in stagnant water, and numbers of them are usually to be found on the stems and leaves of plants near the edge of a pond. The commonest species is a tiny little creature about $\frac{1}{100}$th of an inch in length, which is invisible to the naked eye. Under the microscope, it is seen to be a colourless, jelly-like bit of animation. Its body is soft and changes shape as the amoeba moves along in a flowing kind of motion. It is made up of a single living cell, complete with outer membrane, cytoplasm, and nucleus. It is an animal organism, showing the characteristics of response, metabolism, and reproduction. It is but one cell, one of nature's living units, a brick on the loose.

The amoeba is surrounded by water, but appears to be a distinct living unit. However, its small body is about eighty-five per cent water. As far as we can tell, the water in the internal parts of the amoeba has the same properties as the outside water through which the tiny animal moves. If the internal water is removed by drying, the amoeba, as we can know it, ceases to exist. The water within the amoeba arrives there by passing through the

membrane at the outside surface of the cell. Water moves back and forth through the cell membrane quite readily, so that a molecule of water within the amoeba is truly here today and gone tomorrow, or sooner. Oxygen and carbon dioxide also move back and forth across the membrane, in and out of the amoeba. Iron, phosphorus, nitrogen, and many other substances are also exchanged between the inside and outside of the cell through the cell membrane. The components of the cell are chemicals, and when these chemicals are extracted from the cell, they are not living in the sense that the cell lives.

If we arbitrarily say that what is within the cell is living amoeba and what is outside is environment, we may make a sharp distinction between organism and environment. But then, water becomes 'living' as it enters the cell, and it 'dies' as it passes out through the cell membrane. It would seem simpler and more logical to consider water as being the same stuff on either side of a cell membrane. As a consequence of this assumed simplicity, the external environment is continuous with the internal organization in so many respects that no sharp line can be drawn between them. The organism, then, is not completely separable from its surroundings. What has been described for the amoeba is the likely case for any cell, alone or one of many millions in a complex animal body.

The body of an organism, amoeba or any other, is constantly being broken down and reformed. The raw materials for the building and operation of the organism come from the environment. And they must ultimately return to the environment. A human body weighing 155 pounds is composed of about 100 pounds of oxygen, 15 pounds of hydrogen, 28 pounds of carbon, $4\frac{1}{2}$ pounds of nitrogen, 2 pounds of calcium, $1\frac{1}{2}$ pounds of phosphorus, $\frac{1}{2}$ pound of sulphur, $\frac{1}{4}$ pound of sodium, and a few odds

and ends, such as enough iron to make a couple of small nails. These materials all come from the environment, but such an array does not constitute a recipe for making people. The difference between a human being and such a pile of chemicals is one of organization. At least that is the main difference from a physical point of view.

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The importance of environment to an organism and to this whole problem of life is shown in the case of the spores of bacteria. Bacteria are microscopic one-celled organisms. They are generally considered to be a simple type of plant. As everyone knows, some disease germs are bacteria. Many different kinds of bacteria are responsible for the rotting of food, decay of dead bodies, fertility of soil, and so on. Bacteria are very efficient in metabolism, and they also reproduce at fantastic rates. Many species of bacteria are called spore-formers. If you were to use a microscope and look at a thriving group of spore-former bacteria, you would see two types of cells. The more numerous type would appear as typical bacterial cells, but here and there among them, there would be one that is round and thick-walled. These are spores and are somewhat like seeds. If the bacterial colony should become dried up, all the cells would die, except the spores. The spores of bacteria are blown about the countryside by the wind, or they may be carried by water, or in the fur, feathers, and feet of animals. When one of them falls into food, or into some such suitable environment, it germinates like a seed. Upon germination, the spore produces a typical bacterial cell, which immediately starts metabolizing and reproducing. Thus a new colony of bacteria is started.

A biologist can raise bacteria in the laboratory under

conditions which will lead to the production of millions of spores. These spores may be dried in an oven and stored in a bottle. Even after years in a bottle, they will germinate and produce bacteria if put in the proper environment. During the time that they are dry and stored on a shelf, they are biologically inactive. They do not respond or reproduce, and our most sensitive instruments cannot detect any metabolism. According to how we measure life, they are not living. Certainly, the dried spore has a potential for living, but the realization of that potential is strictly dependent on the spore's being in a suitable environment. Thus, we are led to believe that the 'living' of the spore comes from its internal make-up and organization, and also from its being in surroundings which make its living possible.

Most biologists are willing to say that the dry bacterial spore is alive, even though it does not show the characteristics of life during the time that it is in a dry, quiescent state. It is in a state of suspended animation, as it were. This interpretation involves an assumption, however. We have to assume that the life of an organism – even that of as lowly a creature as a bacterium – includes something more than we can observe and measure. But in this idea we encounter an assumption which is unnecessary from a scientific viewpoint, and which borders on anthropomorphism. Scientifically, we must play it safe and say only that the spore is viable – that is, capable of living.

What has been said of spores is true to a lesser degree of the seeds of plants. But it is generally not at all the case with the eggs of animals. Seeds of higher plants usually show a reduced, but quite measurable, metabolism. Eggs display a great deal of metabolic activity, and very few are ever capable of a sporelike period of in-

activity. Exceptions do occur, however, and a very interesting example took place recently in California. A number of dry lake beds are to be seen in the Mojave Desert. Many, many years ago these depressions contained water and were true lakes. Then, as the climatic patterns of the continent changed, the lakes dried, and the area became a desert. In September 1955, a cloudburst occurred over a part of the Mojave Desert. As a result of the storm, one of the old lake beds filled with water to a depth of about a foot. Then something even more fantastic than a cloudburst happened; millions of little inch-long shrimplike animals appeared in the water. A few centuries ago the appearance of shrimp under such circumstances would have been explained as spontaneous generation. But we do not believe in spontaneous generation any more; so the matter was investigated. It was found that the shrimp were hatching from eggs that had been in the dry lake bottom. The eggs had lain in the dried mud under the desert sun for uncounted years. Millions were still viable when their proper environment occurred once more. As in the case of the bacterial spores, we are faced with the question of whether the dried eggs were living in the same sense that the shrimplike creatures they formed were living.

According to the principle of biogenesis, all life comes from pre-existing life. This important biological principle was explored in Chapter 3. The shrimp eggs and bacterial spores were, certainly, produced by previous shrimp and bacteria. And they, in turn, eventually developed into organisms similar to their ancestors. It is the delay, the period of suspended animation, which concerns us. The key to their living in a dynamic, measurable way was withheld. When that key condition was again furnished by the environment, the organisms were

able to live in a scientifically measurable manner. Thus, we can say that the spores and eggs were still viable, and our concept is consistent with the principle of biogenesis.

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All organisms are dependent on a suitable environment for their day-to-day and year-to-year livelihood. It is surprising and perhaps a little shocking to find that the environment is more than just a stage on which the drama of life is enacted. It appears to be a fundamental part of that elusive process called living. In the complex organization of an organism, the environment provides essential factors. If a single chemical substance were to be pointed out as the key to life, that substance would be water. A living cell is over three-quarters water. It is water that brings bacterial spores and shrimp eggs 'back to life'. The long evolutionary struggle of plants and animals has been toward greater independence from the environment, greater utilization of and dominance over their surroundings. But without water, all perish; without water nearly all chemical reactions fail. Water is as close as we can come to the ancient futile hope of finding an 'elixir of life'.

The idea that the characteristics of life appear only when the internal and external conditions are just right for it, leads us to think of life as a process. Inevitably, we arrive at the idea that life is not something fundamentally distinct from matter-energy and space-time. We reach the concept that the phenomena of life are properties which emerge from highly organized physical systems of a particular type. The properties or characteristics of the living process are always associated with a particular sort of chemical and physical organization. An object so organ-

ized, we call an organism. This way of interpreting the existence and behaviour of living things is known as the *theory of emergent properties.*

The theory of emergent properties is really an attempt to account for the observed characteristics of many things besides living organisms. The theory and the sort of picture it gives us of the world is worth some exploration, as it is a popular concept among scientists. It is also an attempt to unify biology and physics, and to bring the behaviour of animals into agreement with the behaviour of strictly physical systems.

The emergence theory may be made understandable by the example of a simple chemical compound, such as water. As we have seen, water is of considerable biological importance. Water molecules are each made up of two atoms of hydrogen and one atom of oxygen. Hydrogen is a light-weight inflammable gas. At a temperature of 423 degrees below zero it becomes a liquid, and 434 degrees below zero it freezes. Oxygen is also a gas at ordinary temperatures. At 297 degrees below zero, oxygen becomes a liquid; at 360 degrees below zero it freezes. Oxygen and hydrogen react with each other with a violent release of energy. Chemically the reaction is a simple oxidation of hydrogen, to produce water. Water shows characteristics which are quite different from those of either hydrogen or oxygen. Water is a liquid at ordinary temperatures. It freezes at 32 degrees, and it boils at 212 degrees. It expands as it freezes, is a good conductor of heat, and has a number of other very important properties.

The properties of water do not appear to be in any way related to the characteristics of hydrogen and oxygen. The characteristic physical and chemical properties of water appear to depend on the way in which hydrogen and oxygen are joined in the water molecule. In other

words, the properties of water *emerge* from the organization of the molecules.

Starch and cellulose are both complex carbohydrates. In both starch and cellulose, simple sugar molecules are hooked together in long chains to form very large, complex molecules. Exactly the same type of small sugar units are present in both, but the manner in which they are linked together is different. Apparently, the difference in organization accounts for their having such different properties. Starch is an important food substance, easily digested and chemically reactive. Cellulose is the stuff of which paper is made; indigestible, tough, and chemically stable. The properties of starch and cellulose are not predictable from the properties of the sugar molecules themselves. The properties arise from the manner in which the small sugar molecules are organized into long molecular chains. In other words, the observable, measurable, and useful properties of the two substances emerge from the particular way they are organized. The properties of starch and cellulose are not to be accounted for solely on the basis of the nature of the smaller particles that go into their make-up.

The emergence of particular properties from the physical organization of an object or substance is an idea which applies to man-made things as well as to naturally occurring objects. A supply of steel, copper, and rubber may be used to construct a calculator, or a motor-car, or a submarine, or an iron lung. Each of these machines shows different characteristics. and is good for different purposes. Their important properties emerge from the way that the steel, copper, and rubber have been organized. Their properties, their functions, and their purposes are not predictable from the properties of the raw materials going into their construction. So it is also with

human organizations, groups of people working together. The properties and characteristics shown by an organized church group will be different from those of a sales organization. Even though some members of one may also be members of the other, the groups will differ because of different internal organizations and purposes.

The whole concept of emergent properties is well within our common experience. And it seems a logical and useful way to look at the great variety of things we see in the world about us.

An organism is far more complex than water, starch, calculators, and the other examples we have examined. The one-celled animal, amoeba, which we met earlier in the chapter, is a simple little creature. The amoeba may seem to be a simple animal when it is compared to more highly organized forms, such as a dog or a tree. But even so, the amoeba is a very complex bit of living stuff. From the intricate structure of that little being, a definite set of properties emerge. These properties include the behaviour and form of the amoeba, and the characteristics of response, metabolism, and reproduction, according to which we say that the small creature is alive. The dried bacteria and shrimp eggs did not show the characteristics of life because their internal organization was not such that the properties of life could be produced. The addition of water to their structure resulted in the emergence of the properties by which we identify the living. Dehydrated spores and eggs are a kind of 'Instant Life'.

The theory of emergent properties is not a new idea. It has been with us since the time of Aristotle and the ancient Greek philosophers. It has been brought out to account for evolution, growth and development, behaviour patterns, and a host of other things. The emergence theory has the very important effect of uniting the world

of biology with the world of physics. According to it, life is not a distinct thing, different in some intangible way from non-living matter. Life is a group of characteristics which are shown by an object which is highly organized in a particular way. Biochemistry and physiology are branches of science devoted to the study of the physical details of that organization.

The more complex the organism, the more complex and purposeful will be its emergent properties. It is, by this line of reasoning, idle to ask whether or not an enzyme, virus, or gene is alive. They each show properties which come from their structure and physical organization. If some of these properties are similar to some of the characteristics of an organism, they must be considered living to at least that extent.

The theory of emergent properties serves to define the position of biology in science as a whole. It shows us clearly what kinds of concepts of life are consistent with the structure of scientific knowledge. Early in our discussion of organisms, in Chapter 8, it was pointed out that life can be defined only in terms of the characteristics of living things. We defined an organism as a physical system showing the characteristics of response, metabolism, and reproduction in a coordinated and self-regulating way. We then explored a number of aspects of biology, and found that different organisms were remarkably similar in their functions and organization. What effect, we may now ask, does the theory of emergent properties have on our concept of an organism?

The theory of emergent properties tells us that from the particular complex make-up of an organism certain properties emerge. These emergent characteristics include metabolism, response, and reproduction. In other words, the theory merely leads us back to our original definition,

without adding to our knowledge or understanding of the living world. It does not answer the question of whether or not there is more to a living thing than its physical system. No light is shed on the question of whether there is a spiritual or vital component within the living system.

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Man has always tended to people the world about him with spirits. Living creatures, especially animals, have been thought to be inhabited and controlled by an intangible spirit, or soul. No doubt this belief arose originally (and still arises) from the feeling of every person that he is more than just a body, more than a mere machine. Intuitively, I feel that within my body there is the conscious 'I', the real 'me'. This central soul is more than simply a property which emerges from the complex machinery of my body. Although I know that I will die, perhaps tomorrow, I cannot imagine a state of non-existence. So I must think of my soul as having an infinite property, an eternal existence which must ultimately be of a non-material nature. The soul is, therefore, assigned an objective reality which transcends the purely material body.

This way of thinking of oneself leads one to think of other people in the same manner, as also containing an unquenchable soul. Such a view of life is also easily transferred to our ways of thinking about the life and being of other creatures. This anthropomorphic view of the world sometimes becomes very extreme. Spirits are often ascribed to plants and non-living objects, as well as to man and animals. A sixteenth-century book on natural history included a discussion of the antagonism or enmity that was supposed to exist among different things. It was,

for instance, believed that there was a 'notable disagreement' going on between garlic and lodestone. Lodestone is magnetized iron ore, and it will, of course, attract other iron objects to itself. Magnetism was very mysterious – even supernatural – to the people of that century. It was believed that the enmity between garlic and lodestone was so intense that a piece of lodestone which had been smeared with garlic would immediately lose its magnetic abilities. It seems odd to us, today, that such a belief could be held, since testing it would be so simple and conclusive. We must remember, however, that in the sixteenth century, the 'study' of nature was deductive, not inductive.

The question of whether or not living organisms differ fundamentally from the non-living is still unanswered. It is well known that an organism is a bundle of precise chemical reactions. It is also well known that many of the characteristics of an organism are properties which emerge from its exact and peculiar physical and chemical organization. These things we know from observation and measurements. We also know that when some force – disease, accident, old age – renders that organization inoperative, the characteristics of an organism are no longer apparent. But all of this does not answer the question, 'Is the organism nothing but a machine, however complex its organization, and however amazing its emergent properties? In addition to its material complexity, is an organism organized and maintained by some sort of a spirit of life, a vital force?'

Each organism seems to act with some degree of purpose. Each organism, however lowly, however simple, appears to be possessed of a vitality which gives the creature its life and its purpose for existing. It is nearly impossible to study the embryonic development of an

animal without becoming entranced by the apparent forces that are striving for expression as a precisely designed, fully functional being. It is as though a tremendous life force were building and organizing a creature by a pre-existing blueprint, and through that organism were achieving some definite goal.

The question is whether or not such a vital force is an actual, objective part of the universe. Or is it just a man-made convenience as a way of thinking, an item of hope? This has long been the subject of great controversy. Biologists who favour the concept of vital force are called *vitalists*. Vitalists claim that a vital force is necessary for the existence of any form of life. Every organism has a material body and functions by way of a great array of chemical reactions, and by these material mechanisms makes its way in the world. But, the vitalist says, these complex mechanisms could not have arisen by chance alone. Nor could they be maintained and perpetuated on the face of the earth by just their own physical properties. The vitalist believes that it is necessary to assume that there is a universal force which is responsible for the organization and the maintenance of the living processes. Each individual organism is, then, an expression of that vital force.

Opponents of the vital force idea are called *mechanists*. The mechanists claim that the whole idea of vital force is sentimental nonsense. Such a sentimental idea arises only because we still know so little about the details of the mechanisms of life. Every phenomenon has a material mechanism at its base. There is no reason to believe that life is different from other things in this regard. Life is nothing but a set of properties which emerge from the complex organization of an organism. And though we are still abysmally ignorant, we shall eventually under-

stand the living process, even to the point of being able to produce it synthetically.

These two viewpoints – vitalism versus mechanism – represent a crossroad in ways of thinking. It is, however, a crossroad of great importance. If one turns toward vitalism, one turns toward the concept of the human soul, toward the idea of God, toward a universe in which life has a meaning beyond its immediate existence. Those who tread the path of mechanism, on the other hand, wander in a bleak and blind universe, where the living are distinguished from the non-living only by virtue of their greater complexity. Alone, naked in the universe, the mechanist must create his own goals and responsibilities, and in his own fleeting existence find the meaning of his world. There have been many attempts to point out a middle way, but there is no middle way. Either there is or there is not such a thing as a vital force in the universe.

What is the scientific status of the question of the existence or non-existence of vital force? The answer is very simple; it has no scientific status, whatsoever. However simple that answer may seem, it is treacherously misleading, and requires a good bit of explanation. In spite of prolonged discussions and heated arguments on the subject in biological circles, the problem is not a scientific question. It is one of philosophy. As with other philosophical choices, you can 'pay your money and take your pick', and defend your stand against all comers. Like all thinking individuals, scientists have philosophies. Their philosophical beliefs inescapably colour their interpretations of scientific knowledge. But the inescapability does not make their philosophies scientific.

Science is knowledge of the material universe, and this knowledge is obtained by measurement of the things and forces found in that universe. It is not possible to develop

a scientific concept of a force which cannot be detected and measured in some definite and objective way. Thus far, no one has been able to devise a method for measuring vital force. If some scientist should discover a means of demonstrating it in a measurable way, the concept of vital force would then begin to develop some scientific prestige.

The philosophy of mechanism takes advantage of all the measurements of form and activity which have been made. There is no shortage of evidence that organisms are made up of myriads of measurable processes. However, the mechanist's assertion that an organism is *nothing but* material mechanics is an assumption which cannot be proved by experiment. There is no way to prove that there is nothing beyond what can be observed and measured. The philosophy of 'nothing but' is a narrow and dogmatic metaphysics.

The vitalist, on the other hand, asserts that an organism cannot be fully accounted for on the basis of being nothing but a well-oiled machine. But he cannot prove his assertions either, for he has to make an untestable assumption. The vitalist must assume that vital force is an organizing force which cannot, itself, be yet another mechanism. Thus, it is seen that both the mechanist and vitalistic ways of looking at the living world involve assumptions that cannot be tested.

Biologists who are concerned with studying the behaviour of animals have a rule of thumb known as the 'Harvard Law of Biology'. With all the respect due the institution of the same name, the 'Harvard Law' is not a scientific law at all. It is but a happy device to keep biologists from losing their sanity. The 'Harvard Law' is that 'Under precisely controlled experimental conditions, animals do as they jolly well please'. To the vitalist, this

rule is an admission that we cannot reduce an organism to nothing more than a complex array of mechanisms. To the mechanist, it means only that we still have much to learn about the mechanisms that are to be found in the intricate make-up of an animal.

There have been a number of attempts to settle, by experiment, the vitalism-versus-mechanism dispute. One of the best-known efforts along this line involved experimental studies on the sea urchin. The sea urchin is a strange little animal that lives on the ocean floor. It is related to the starfish, in that it belongs to the same large animal group, or phylum. Sea-urchin eggs have often been used in experiments on embryonic growth. They are well suited for this type of research because they are easily obtained, and their development is readily observed. Hans Driesch, a well-known German biologist of the last century, used sea-urchin eggs for growth experiments. Driesch was a vitalist, and at one time he thought that he had devised an experiment which might settle, once and for all, the controversy between the two schools of thought.

As do all other animals, the sea urchin starts out in life as a fertilized egg-cell. That cell divides to become two cells. These two cells divide to become four; the four become eight, and so on. As the number of cells increases, the individual cells become specialized, and the form of the young sea urchin begins to appear. During the time that the egg divides again and again, the cells produced do not just rattle around loose. They stick together, so that a clump of cells is produced. Different regions of the clump eventually develop into different parts of the sea urchin.

Hans Driesch had the idea that if the organism were only a machine, the potential of all of that machine must

be present in the egg-cell. When the egg-cell divided into two, the potential for forming half of the organism should be in one of the cells. The other cell should then contain the potential machinery of the other half of the organism. Now, if the two cells could be separated experimentally, so that they would have to develop separately, the best that each could do would be to develop into only one half of an animal. Any better than that would be a positive demonstration that an organizing vital force was at work.

Through the use of a vibrator, Driesch was able to separate the two cells produced when a sea-urchin egg divided. Anxiously and patiently, he observed the growth and development of the separated cells, as they divided and redivided to form clumps of embryonic cells. He watched them with mounting excitement as they formed young sea urchins. Each of the original cells developed into a complete, normal sea urchin. From one egg, he had obtained two sea urchins. No half-urchins had been produced. He interpreted his experiment as being a positive and undebatable demonstration of a vital force. Only some sort of an organizing, purposeful force which was more than mere mechanism could have been responsible. Nothing less than that could have produced two complete organisms where there should have been but one. No machine, torn in half, could accomplish such a thing.

The vitalistic interpretation of Hans Driesch's experiment is not accepted today. Driesch knew nothing of genes, and he could not have known that when the egg divided, a full set of genes went into each of the cells produced. Each cell then contained the potential for becoming a complete sea urchin. In some way still not fully understood, two cells sticking together develop as one two-celled unit, instead of two one-celled units. Thus, the experiments of Hans Driesch did not prove the existence

of a vital force, since his results can be adequately accounted for on a mechanistic basis.

In the shadowy border-zone between legitimate science and outright pseudoscience lies a subject of study called parapsychology. Parapsychology deals with clairvoyance, mental telepathy, and such related phenomena. The subject is much too large and controversial to review here, but there is an aspect of it that touches on the idea of vital force. The twentieth-century leader of parapsychology has been J. B. Rhine, who has written several books and many magazine articles on the subject. Rhine's interest is in mental telepathy, which he calls ESP (Extra-Sensory Perception). ESP is, supposedly, perception which is not to be accounted for on the basis of any sense organs or nervous mechanisms. It is, according to Rhine, from the force of the mind itself. It is, therefore, not to be described in terms of mechanisms, mere chemical cause-and-effect relationships. ESP is apparently quite comparable to vital force, in that it is supposed to be a force or effect that transcends the chemical and physical material mechanisms of the nervous system. Most scientists do not accept Rhine's work because they feel that his experimental methods are not adequately standardized and controlled. His conclusions are also questioned because the term 'extra-sensory' implies going beyond scientific principles. That is too much mysticism for most scientists. ESP concepts encounter the same legitimate scientific objections as do ideas concerning vital force.

In all branches of science, we start with the fact of the existence of an observable thing or event. So too in biology. Here, an organism is taken as one of nature's hard, irrefutable facts. We call it living, and define life in the terms of the measurable characteristics of living things. We search for the simplest organism, thinking that it will

allow the simplest definition of life. The organism can be divided into a host of simpler phenomena, or it can be compounded into phenomena of greater complexity, as in the study of social forms. But always there is a measurable mechanism to be detected, which will describe what the organism does, what characteristics it displays. Since such measurements are both the goal and the limitation of science, it is inconsistent to insist that we hold concepts of what might lie beyond. An intangible vital force responsible for directing and maintaining the complex organism is an untestable, complicating, and quite unscientific idea.

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Followers of the mechanistic philosophy also have their difficulties. Strict mechanism was an easy philosophy to hold during the nineteenth century. The universe was thought to be a huge machine. Although obviously intricate, it did not seem so mysterious from a scientific standpoint. Every occurrence was to be accounted for on the basis of strict cause and effect. There was, ultimately, no such thing as chance. What happened at one moment was the natural and inevitable result of what had happened at the previous moment, and, in turn, determined what was to happen in the next moment. The future was entirely determined by the past, and in such a system there was no possibility of any freedom of choice. Man and all other living things could not possibly be more than machines since the whole universe was irreversibly determined from the beginning of time. The existence of an organizing, directing, life-giving, vital force would imply a degree of freedom. It would imply that living creatures display some independence from absolute cause and effect, some ability to flaunt the universal mechanism. Such an idea was contrary to all scientific knowledge. It

was quite obvious, therefore, that an organism could not possibly be more than an extremely complex group of chemical and physical processes, from which the properties of life emerge.

The twentieth-century revolution in science blew a large hole in this idea of a completely determined universe. The assumption of cause and effect broke down at the very place it was most needed – among the ultimate particles of the physical world. A mechanical, cause-and-effect universe can no longer be considered a scientific certainty. Mechanism, like vitalism, has become a philosophical choice.

In place of the certainty of inflexible cause and effect, we have to explain natural phenomena on the basis of probability. Scientific laws, principles, and theories have become statistical descriptions of what happens in the world. If nothing more than chance, pure probability, should be in operation, the universe would be a mere random collection of particles. But the world is obviously not a random thing; it is organized and integrated. Many scientists have thus been led to believe that there must be some anti-probability force in operation, which is responsible for the definite things and happenings we observe. A man, a tree, a virus, or a gene cannot be the result of just pure chance, but must be organized and maintained by a force or agent which shifts and shapes probabilities. This has been called anti-probability or anti-chance. From a biologist's point of view, it may as well be called vital force.

The philosophy of mechanism suffered another blow when the theory of relativity was developed, and its consequences were explored. It was then realized that a scientist, a human mind, is not an absolute observer. His observations and measurements are not absolute descrip-

tions of real things; they are relative to his position as an observer. And they are relative to the tools he uses. Thus, the observer becomes part of the experiment. Scientific ideas and theories are not necessarily descriptions of what is objectively real, but are descriptions of a reality which is relative to the human mind. And the mind itself may shape and organize a reality from a random chaos. Our mental activities, the mind of man, may have some of the characteristics of an anti-probability, even a vital force.

Matter, the good old hard stuff that the world is made of, has turned out to be rather mysterious. Matter can be turned into energy, and we have some bombs to prove it. Energy can also be made into matter. The subatomic particles of matter seem to be packets of energy. A material universe is, then, no different from an energy universe. This sort of consideration led the eminent British physicist Sir James Jeans to the conclusion that the universe may be basically spiritual in nature.

Vitalism and mechanism represent the horns of a dilemma. Neither philosophy is more consistent with science than is the other. Both involve untestable assumptions as to what, if anything, might exist in addition to what we observe and measure. The mechanist says that nothing lies beyond the reality of what we observe. The vitalist claims that there must be something more than that. If a biologist or biochemist should discover how to create an organism in a test tube, the dilemma would still be unsettled. The mechanist would say, 'Aha! I told you so.' The vitalist would reply, 'At last, we have learned to use vital force.' And there the matter would stand – still unsettled.

To return, now, to our original question, 'Is the world of physics and the world of biology one world?' From the standpoint of science, it is one world. It is one world

because the assumptions, the methods, and the limitations are the same in biology as in physics. In either case, we are limited to observing and describing, experimenting and measuring. In both branches of science, the occurrences of things and events are taken as fact, and these phenomena are known to us only by their behaviour, their objective, measurable properties. Beyond this we cannot go. The reality ascribed to either an electron or an organism can be no more than its behaviour and properties as we can measure them, under the simple assumptions that form the foundations of science.

The limitations imposed on science by its very structure are much more serious barriers in biology than in the physical sciences. Biologists are daily faced with the mystery of life, and the magnitude of that mystery sometimes seems overwhelming. What we have learned of living processes is but a thin coat of glossy varnish, smoothing over and hiding our astounding ignorance of what really goes on in an organism.

The twentieth century has, in its first half, seen a scientific revolution. That revolution came mainly from physics. It is to be hoped that the second half of the century will yield a biological revolution. Biology sorely needs new horizons, new concepts, and new intellectual freedom. The challenge of the living world has not yet been met. The great intellectual conquests still lie ahead.

10

WHY?

'Science fishes in the sea of reality with a particular kind of net called the scientific method, and there may be much in the unfathomable sea which the meshes of science cannot catch.' *Sir James Jeans*

A SMALL boy waited expectantly, sitting upright and eager in the front seat of the family motor-car. At his side, behind the wheel, his father fumbled momentarily with the ignition key, and then started the engine. The wondering eyes of the five-year-old watched, and then the question came.

'Daddy, why does the car go?'

'The car goes because the engine makes the wheels go around.' This answer satisfied the youngster, but not because he had any notion of how an engine can turn wheels. Indeed, he could have little or no concept of mechanics and engines. The answer was satisfactory because he had been told by no less an authority than his very own father. That was sufficient; the engine makes the wheels go around. And that is why the car moves.

As father and son drove on, the child was curious about many things. Seeing a dairy herd in a field, he asked, 'Daddy, why is a cow?'

'Cows give us milk and meat,' was the reply.

Within the experience of a small boy, this was a perfectly logical answer. Their importance as providers of milk and meat made cows fit into his world, and their usefulness justified their existence.

A few moments later, a small rabbit scurried across the road.

'Daddy, why is a bunny?'

'Please be quiet, son. Daddy is busy driving.'

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To ask the question 'Why?' is as old as the human race, for man is an enormously curious being. To wonder why things exist and why events occur is, apparently, a universally human trait. As the scope and depth of human knowledge increases, the question of why becomes more sophisticated, and the answer must be more than an authoritative retort. It must also be more than a description of mechanical cause. The question becomes a query concerning the necessity and purpose of things being as they are in this world of ours.

A child or an adult might ask the question, 'Why is the sky blue?' There are two ways to answer this question. One answer is, 'The sky is blue because God made it that way.' Such a dogmatic explanation of the blue sky is basically unsatisfactory. It is unsatisfactory simply because it closes the door on further inquiry. It is the same as saying that the sky is blue because it is blue, and there is no more to be said on the subject. From a scientific standpoint, it merely restates the observation that the sky is blue, and does not answer the question. Such a dogmatic explanation of the sky's being blue makes no addition to human knowledge, and it does not lead to a better understanding of the natural world. It must be realized, of course, that the question, 'Why is the sky blue?' is an absurdly simple example of the things that people from all periods of history have wondered about. It is important to appreciate, however, that the basis for rejecting a dogmatic and authoritative explanation of even so sim-

ple a question is exactly the same as the reason for rejecting such answers to more complex problems.

The second way to answer the question as to why the sky is blue is to explain it on the basis of the physical mechanisms which cause the sky to appear to be blue. Particles in the earth's atmosphere have the effect of scattering the light-waves coming from the sun. Large particles scatter all wave-lengths of light equally. Very small particles cause only the short wave-lengths to be scattered. These shorter wave-lengths therefore appear to be coming to the eye from all parts of the sky, rather than from just around the sun. The short wave-lengths of light look blue to the human eye. Thus, the sky is blue.

Such a physical explanation of the blue sky does not prevent further investigation of the matter. More information may be obtained by studying the characteristics of light, and light diffraction, and light polarization, and of the composition of the atmosphere itself. The whiteness of clouds and the redness of sunsets are to be explained by the same line of reasoning and the same group of physical characteristics. This approach to the problem opens the door to a great area of physical science. It brings the phenomena of the blue sky and such things as the optical principles of the microscope into one science. The blue sky is explained scientifically in terms of the physical phenomena which result in a blue sky, and this has the effect of fitting them into a cause-and-effect chain of events. Such is the answer of science to the question, 'Why is the sky blue?'

It might be argued that the scientific answer to the blue-sky question does not settle the matter any more than did the dogmatic statement that the sky is blue because God made it that way. One answer says that it is blue by creation; the other says that it is blue by mechanism.

Neither answer gives us any clue as to the logical necessity for the sky's being blue. In one sense, the question 'Why?' is a demand for an understanding of the necessity of things and occurrences being what they are.

Logical necessity is not always apparent in scientific theories or scientific ideas in general. As long as we cling to the attitude that all phenomena are determined by strict cause and effect mechanisms, the logical necessity for a particular effect is apparent, at least in a vague sort of way. When we understand something well enough for its occurrence to be predicted mathematically, it has a logical necessity from a scientific standpoint. Its occurrence is logically inescapable, and has the same degree of necessity as has the mathematical logic used to predict it.

This point may be at least partially illustrated by a purely mechanical model. Suppose that we have two gears or cog wheels that mesh. If one turns, the other must also turn. The larger of the two cog wheels has thirty-six teeth; the smaller has but twelve. When the larger gear is made to turn one complete revolution, the little cog wheel will turn three complete revolutions, as a consequence. It is a completely inescapable result. Its logical necessity is the same as the logical necessity of $\frac{36}{12}$ being equal to 3, the gear ratio between the two cog wheels.

To view natural occurrences on exactly the same basis as we looked at the two cog wheels would be entirely too naïve. Natural phenomena are much more complicated and less mechanical than a set of gears. The idea that an occurrence is an effect which is a logically necessary result of a group of previous causes is still the basis for most scientific explanation. However, the principle of uncertainty has forced us to adopt the attitude that we must consider natural laws and scientific principles as statements of probability, rather than descriptions of rigid

mechanisms. This results in our being less sure of the logical necessity of an event. For an event which is necessary should be inescapable, rather than a kind of statistical average. For purely practical reasons, scientists continue to consider an event as a necessary consequence of a mechanism, even a statistical mechanism. We are still quite at sea, however, in regard to the logical necessity of the very existence of the mechanism itself. To return to the example of the two cog wheels, it may be quite apparent that both wheels must turn if force is applied to one of them. We can study and describe that effect, and come to a thorough understanding of the operation of gears. But nothing in the study of the gears themselves will tell us anything of the necessity of their very existence in the world.

It is the good and proper business of science to answer the question of why events take place as we see them, to answer such questions as why the sky happens to be blue. The manner of answering, however, is limited to an explanation of the measurable causes and effects within an existing physical system. It is often said that because science is limited in this manner, it cannot answer the question 'Why?' but answers only the question 'How?' That is, the physical explanation for the blue appearance of the sky does not tell us *why* the sky is blue, but only *how* it comes to look blue. This distinction between *why* and *how* is not complete, however. Within its peculiar limits, science is an attempt to answer the question 'Why?' Its greatest success is, certainly, in explaining phenomena in terms of how they occur, the physical mechanisms involved. But it is also an attempt to shed some glimmer of light on the necessity of events occurring as they do.

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The third and most abstract and difficult meaning of the question 'Why?' has to do with the problem of *purpose*. For what purpose does an object exist, a phenomenon occur? If we understood not only the mechanisms and the logical necessity, but also the ultimate purpose of the complex world about us, human knowledge would be complete. The last chapter of science would have been written; the last philosophical riddle would have been solved. Basking in the reflected glory of a universal meaning and purpose, the human mind could, at last, cease its restless wandering and groping after truth.

If a person should ask, 'Why is the sky blue?' he might listen patiently to the scientific explanation of how the sky happens to be blue. However, the answer might not satisfy him, and he might counter with, 'Yes, but for what purpose is the sky blue?' The question seems childish, and hardly worth a serious reply. It is trivial to demand that some ultimate or universal purpose be served by the sky's being blue. Certainly we will not find the answer in the body of knowledge called science. A study of the physics of light and atmosphere is limited to observations and experiments and such measurable and predictable phenomena. In no way do we thus gain any inkling of purpose being associated with a blue sky. The question may be dismissed as being quite unimportant and scientifically irrelevant.

'For what purpose does a man exist?' Is this question as trivial and childish as the question, 'For what purpose is the sky blue?' One of the central problems in human thought is that very question of the purpose of human existence, the purpose to be found in the universe as a whole. Art, religion, and philosophy are all concerned with the problem of the meaning and destiny of man. Religions are based on the assumption that the human

life has a meaning outside of its immediate existence, that some universal purpose is being promoted in the existence of man. Since the dawn of human reason, much thought and effort has revolved around the problem of the meaning and value of the human life, the Gordian knot of purpose.

Scientifically, the question of the ultimate purpose of a man is as trivial as the question of the purpose of the blue sky. It is, quite bluntly, not a question that falls under any category of natural science. Such an abrupt dismissal of the problem of purpose requires considerable explanation. Many people have felt that philosophy, religion, and other branches of human knowledge have failed to demonstrate that the human life serves any real purpose, outside of its momentary existence. Because of the exactness of scientific knowledge, and because of the tremendous success enjoyed by science as a whole, they have looked to science for the answers to the question of plan and purpose in the universe.

Few scientists would deny the possibility that purpose may be a very real and important part of the universe and the human life. Concepts of over-all purpose are not part of scientific knowledge because any series of events may be interpreted in different ways. A whole range of viewpoints is possible, from the assertion of purposeless chance to the invocation of divine guidance toward some glorious goal.

A cause-and-effect series of events might be interpreted as having the final event as the purpose of the whole cause and effect chain. This would be something like a slot machine. If you drop a sixpence into a machine which sells chocolate, you do so for the purpose of obtaining a bar of chocolate. The coin sets into motion a mechanical series of events. The final event is the delivery of a bar of

chocolate. When the machine produces the chocolate, it has fulfilled its purpose.

The universe is not like a slot machine. It is a continuing, ever-operating thing, and its events are diffuse and inclusive. And we do not stand outside; we live inside it. If the purpose of an event is nothing more than the occurrence of a subsequent event, there must be some ultimate universal purpose toward which we are forever moving. With this kind of an idea, we cannot deal scientifically. We can deal only with the events themselves.

If we consider the final event of no more importance or purpose than any other event in a series, we can assign purpose and value to the simple existence of an event. If each natural occurrence is considered its own necessity, its own purpose, we are led to a concept similar to Gertrude Stein's most quoted line, 'Rose is a rose is a rose is a rose'. This is not a very satisfactory approach to the problem of purpose, because purpose and value are normally thought of as being responsible for, but external to, the individual event. Scientifically, we can deal only with measurements and observations of events. The event is irreducible, and there is no way to detect what, if anything, lies outside that event. The methods of science do not seem to be adequate tools for the study of purpose. The assumptions that nature is unified, understandable, and can be described in a simple cause-and-effect way do not assume or imply that any degree of purpose is operative in the universe. These basic assumptions do imply, however, that the universe has a design and plan. But toward what purpose, if any, that design is directed, no assumption is made.

Scientific investigation starts with the fact of a thing or occurrence, and strives toward understanding through observation, hypothesis, experiment, and interpretation.

Purpose cannot be measured; it cannot be subjected to experiment. Purpose is something that has to be assumed as being basic truth. And it is not assumed in science. To read any purpose into measurements, to include concepts of purpose in scientific theories would violate the basic scientific principles of simplicity and testability.

Since purpose cannot be measured and dealt with by the methods of science, it must be looked upon as a peculiarly human way of thinking. As a way of thinking, different people may have different ideas on the subject. The sort of purpose to be assigned to a particular event will vary, depending on the viewpoint, the scale of observation. At best we could have no way of knowing whether an electron in the sole of a man's foot is serving the same ultimate purpose as the whole man. Understanding the ultimate purpose of the universe would require an ultimate or universal viewpoint, of which man is obviously incapable. Purpose must, therefore, be considered anthropomorphic and be excluded from science.

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Although the door of science is bolted against it, the idea of purpose persists in sneaking in through the window. It creeps into biology, where it causes all kinds of trouble in the interpretation of behaviour and function. The purpose concepts that creep into biology are not ideas concerning any kind of universal purpose. They are concerned with immediate purpose, which is closely related to function.

It is difficult to study organisms and not become convinced that the world of living things includes a strong element of purpose: the growth and development of an animal from a single egg-cell; the coordinated functioning of the several organ systems; the intricate patterns of

behaviour; the efficiency of specialized adaptations; the tenacity with which the organism maintains itself in a relentlessly disruptive environment. All of these characteristics appear to be directed toward some goal, and to exist for some purpose. The few examples discussed in the following pages are but a small sample of the hundreds of instances in which the biologist comes face to face with the problem of purpose.

Every organism – microbe or monster – is equipped with a physiological means by which waste products are removed from its body. During the course of metabolism, some chemical by-products are formed which are useless or even harmful to the organism. The food which an animal eats is seldom a perfectly balanced diet; there may be too much of this or that particular chemical. These excess chemicals must be disposed of. Useless and poisonous substances may also be found in the food an animal consumes and absorbs into its body. The poisonous ones must be rendered harmless and removed. Every animal eats some poisonous chemicals in its day-to-day diet, but symptoms of poisoning occur only when more is taken in than the body can conveniently handle. The organ system involved in ridding the body of waste products and harmful chemicals is the excretory system. The anatomy of the excretory organs varies widely among different animal forms. These organs range from an odd little structure called a 'flame cell' found in some worms, to the highly developed kidney of man and other higher animals.

The kidney is an amazing organ. Acting as a selective high-pressure filter, it not only removes harmful waste products from the blood stream, but also adjusts blood volume, acidity, and chemical balance. All of the blood in a human body is filtered through the kidneys once in about forty-five minutes. This means that the kidneys

filter about 175 quarts of blood per day. A kidney is a complex, exquisitely constructed organ. Blood vessels entering the kidney branch and rebranch into many thousands of tiny arteries. Each of the little arteries leads to a filter mechanism. In each filter mechanism, some of the liquid and dissolved substances of the blood are forced through a thin membrane into a collecting tube. The walls of the collecting tubes are made up of special cells, which reabsorb the filtered liquid and return most of it to the blood stream. However, not everything is reabsorbed. The cells reabsorb only the molecules that the body needs – water, sugar, vitamins, and so on. Excess salts, water, and the waste products are not reabsorbed, but are allowed to flow on down the collecting tube and out of the kidney as urine.

If, because of disease or organic failure, one kidney is removed by surgery, the remaining kidney will increase in size and take over for both, doing double duty, as it were. The increased activity of the single kidney is quite sufficient to keep the blood balanced and the body free from accumulating harmful poisons and waste chemicals.

It should seem perfectly logical to say that the purpose of the kidney is to keep the blood balanced and chemically clean. That is, after all, its function. Its structure and mechanics seem to be obviously for that purpose. When one is teaching elementary biology, the simplest and seemingly most logical way to account for the presence, structure, and function of the kidney is to say that it is for the *purpose* of excretion and keeping the blood in a healthy steady state. But to say that the kidney is for such a purpose rather than such a function is to be unscientific. It introduces a note of anthropomorphism into what is supposed to be objective knowledge.

Since the functions of the kidney are known, since its role in the economy of the body has been determined scientifically, are we not then justified in saying that its purpose is also understood? If we believed that each species of animal was created separately and outright and in its present 'perfected' form, there would be some reason to believe that the kidney was created for the express purpose of its present functions. But we are not allowed to hold so simple a view of living things. All that we have learned about living things points to the conclusion that present-day plants and animals have evolved from primitive and simpler forms of life. As with the other organs of the body, the kidney has evolved. The evolution of the complex, highly efficient mammalian kidney has been traced down the family tree of life to very primitive beginnings. During the embryonic growth of a bird or a mammal, parts of the long evolutionary history of the kidney are re-enacted in a series of early developmental stages.

Even if the evolution of different organs is taken as fact, it might still seem logical to believe that the kidney is for the *purpose* of excretion and blood balance. Indeed, evolution might well be for the purpose of the creation and perfection of living things, including man. Such an interpretation may well be the most nearly correct of all possible ways of making sense out of the world of nature. It cannot be called a scientific interpretation, however, because there is no way to demonstrate its validity. It is possible to describe any series of natural events as having purpose or as being purposeless. The same is true of the evolutionary history of a species of animal, or of its organs, or of its behaviour.

As far as is known to science, evolution occurs largely through the survival value of small organic variations that

arise by chance. Let us speculate briefly about the possible beginnings of the evolution of a kidney. In a population of very simple, very primitive organisms, most might have no special mechanism for excreting harmful waste products. Each such animal would live but a short time, as it would slowly poison itself with the by-products of its own living processes. If, by chance, one such animal was able to live a little longer than the others, having lived a little longer, it would have a slightly better than average opportunity to reproduce. The favourable variation would be passed on to some of its offspring. Having inherited something of an excretory system, these offspring would also have a better than average chance of survival and reproduction. As time passed, more and more of the population would show the favourable characteristic, as those without it died out, and those with it took their places. A beginning would thus have been made in the evolution of an increasingly efficient excretory organ, or kidney. Such an evolutionary process would continue as long as increased kidney efficiency increased the chances of individual survival. As generation after generation appeared, lived, reproduced, and died, a more and more efficient excretory organ would be evolved. The highly efficient intricate kidney of mammals is the product of a very long evolutionary process.

There is no single place in the evolution of the kidney where it can be said that definite purpose was being served. To be sure, the kidney is a vital organ; without at least one kidney, the animal dies. But the kidney evolved as the result of a systematic, almost mechanical natural selection of variations that arose, apparently, by chance. To assign purpose rather than only function is to read some ultimate purpose into the whole of evolution. As we have seen, ultimate purpose is scientifically indefensible

because it is not needed as a fundamental assumption. Neither can it be observed, measured, or tested.

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An animal is a self-regulating being. It adjusts its position, growth, behaviour, and vital processes according to its surroundings, according to the conditions imposed upon it. An animal in a hot environment seeks a cooler one; if in a cold place, it seeks a warmer spot. If its surroundings are too dry, it seeks moisture. If it is forced to exercise violently, as in escaping a predator, it breathes heavily to provide its organs and cells with the oxygen needed for such violent exercise. When its stomach is empty, the animal seeks food to fill it. Behaviour seems to contain a strong element of self-regulation, as an animal is constantly involved in activities which tend to preserve its life under the best possible conditions. Animals behave as though their activities have purpose, that purpose being self-preservation and the survival of the species. In the things animals do, in the characteristics they show, some degree of purpose seems apparent. Animal behaviour seems to be directed purposefully toward definite goals.

When behaviour is studied scientifically, however, little or no support is found for the notion that animals behave with either purpose or goals in mind. If the goal is removed experimentally, the behaviour may continue, utterly without purpose from a human point of view. Consider, for instance, the egg-rolling behaviour of the greylag goose. This bird builds a nest of sticks and twigs on the ground. If one of its eggs should accidently roll out of the nest, the goose will retrieve it. To accomplish this, the goose stretches its neck out of the nest and carefully rolls the egg into the nest by guiding it with the

back of her bill. Such behaviour appears to be quite purposeful. The goose seems aware that an egg must be returned to the nest, and her action is for the express purpose of retrieving it. But if the egg should slip sideways away from the goose's guiding bill, the bird continues the retrieving motion, even though there is no egg present. Not only that, but the goose will also attempt to retrieve any roundish smooth object which an experimenter may place close to the nest. The goose will attempt to roll objects into the nest, even if they are so large that she cannot possibly handle them successfully. The whole behaviour appears to be an automatic series of actions which is set into motion by the sight of an egg-shaped object near the nest.

A number of other interesting examples of fixed, or stereotyped behaviour are to be observed in the nesting activities of birds. The oyster catcher seems to prefer to sit on big eggs. Its own eggs are rather small, and it will abandon them if offered larger ones of similar colour. It will even attempt to incubate an artificial egg so huge that it cannot cover it.

If a broody sea-gull's eggs are removed from the nest and placed in an artificial nest near by, the gull will sit on the eggs in the false nest only a small part of the time. She will sit on the empty original nest most of the time. If the gull's eggs are moved a little farther from the original nest, the gull will not sit on them at all. She will eat them and sit on her empty nest. The gull shows a certain amount of egg recognition, but when a 'choice' must be made, the attraction to the nest is stronger than the attraction to the eggs.

Animals show many activities which we say are instinctive. Instinctive behaviour may be analysed experimentally into a series of separate behaviour events. The

whole series is triggered or released, by some stimulus. Nest building, mating, egg laying, egg incubation, feeding of young, fighting, and so on, are but a few of these activities. And although they seem to have a purpose in the biological scheme of things the behaviour itself is too automatic and too easily diverted to enable us to assert that purpose is expressed by the individual animal. Once again, it is simpler and more efficient to describe mechanism, while the concept of purpose proves too elusive to be included in scientific interpretation.

The goal of nest building does not appear to be egg laying. The goal of egg incubation does not seem to be the production and care of young. Each of these activities is, as far as is known, a separate behaviour pattern, separately triggered and separately controlled. An objective observer may see that one leads to another and that they all fit into an important biological pattern. But nothing in the animal's behaviour would suggest that the animal itself has any inkling of it. If the animal's behaviour is toward a goal or for a purpose, the goal must be built into the mechanism of the behaviour, and we cannot distinguish it from the mechanism. If the apparent purposefulness of behaviour is simply part of the behaviour mechanism, the idea of freedom of choice drops out of the study of behaviour. That branch of biology is thus simplified and made more consistent with the structure of science as a whole. For there is nothing in the basic assumptions of science that leaves room for the idea of free will. It is assumed that every event is the effect of measurable causes. There is no room here for free will or choice.

Most biologists have long realized that there is a large element of uncertainty which attends the study of animal behaviour. That uncertainty concerns the concept of free-

dom and the ability of an animal to make decisions and choices. In the study of the physical universe, the principle of uncertainty has forced us to face the possibility that pure chance may be a real factor in the universe. Biological uncertainty of the reality of freedom and purpose is a quite comparable principle, except that it cannot be expressed mathematically.

Psychologists and other biologists interested in animal behaviour find it most efficient and simple to deal with motives and behaviour patterns in terms of *drives* rather than *goals*. The difference between drives and goals is more fundamental than might be realized at first. To say that behaviour is directed toward a goal is to imply that the animal is aware of a purpose, and that the purpose is responsible for the action of the animal. To interpret behaviour in terms of drives, on the other hand, is to say that some factor acts as a stimulus to trigger an automatic behaviour. The animal then shows a particular behaviour because a driving mechanism has been set in motion.

An example should help to make clear the distinction between drives and goals. When a hungry cat stalks a bird, it does so in a typical manner. It crawls toward the bird slowly, keeping its body in a low crouch, and keeping its eyes fixed steadily on the bird. The tip of its tail twitches in a typical cat-manner. When it gets within striking distance, it leaps on the bird, eventually kills it, and carries it away to be eaten.

Here is purposeful behaviour; the cat acts as though it has a definite goal in mind. The goal is apparently a stomach full of bird. The whole action of stalking and leaping on the bird is the means by which the cat accomplishes its purpose and attains its goal. In this interpretation of the cat's behaviour, we must assume that the cat possesses a certain degree of consciousness. As was pointed

out earlier, consciousness cannot be dealt with objectively. It must also be assumed that the cat thinks of the bird as an edible object, and purposely and by choice sets out to catch and eat it.

In many ways, it is more effective to think of the cat's behaviour in terms of driving mechanisms. The sight or smell of the bird initiates a stalking behaviour pattern in the cat. The cat just automatically goes into the stalking sequence. The presence of the bird releases a nervous 'switch', setting a mechanism into motion. If the cat were not hungry, or if it were being chased by a dog, or if it were sexually excited, or otherwise distracted, the bird would not have this effect. Other switches would be closed; other mechanisms would be operating. As the cat creeps up on the bird, a leaping mechanism is made ready to operate. The leaping mechanism is released when the bird occupies a certain proportion of the cat's visual field, and the cat then jumps on the bird. Contact with the feathers and body of the bird acts as a releaser for biting behaviour, and the cat kills the bird. The smell and taste of warm blood releases the pattern of behaviour known as feeding, and the cat eats the bird. It is not necessary to assume consciousness, purpose, or choice. The cat did only what it was driven to do, what its evolution had adapted it to do. Here is only a mechanism, a series of events; with this we can deal objectively and scientifically.

Interpreting behaviour in terms of drives and stereotyped behaviour patterns is both convenient and fully scientific. It allows efficient and very fruitful experimental study of animal behaviour. It works nicely in dealing with lower animals. But when higher animals are studied, it seems less appropriate, for their actions tend to show more indications of real freedom and purpose. To study man, the most highly developed living being, and to interpret

his behaviour exclusively in terms of drives and released behaviour patterns, is obviously absurd. To account for Handel's *Messiah* or Lincoln's Gettysburg Address on the same sort of basis as we account for a cat's catching a bird, would represent an idiotic distortion of human intelligence.

We find ourselves backed into a corner, trapped by our own scientific methods. The way out of the quandary is not at all clear, although many psychologists are busily working on the problem. The common-sense experience of freedom, consciousness, ambition, goals, and purpose must be taken as real phenomena. These attributes may not be present in the lower forms of life. They may be properties which emerge only toward the top of the evolutionary scale of life. Biological science may have to be reshaped in fundamental ways if we are ever to learn how to bring the study of these apparently non-mechanical aspects of experience into our science. From where we now stand, the view is foggy, and we must grope cautiously to find our way along. It may well be that we will never have the scientific tools to study these human characteristics. They may be so much a part of our mental make-up that we will never be able to view them objectively. If there is no basis on which we can subject them to scientific study, they must remain outside of science. But in no case is there valid reason for denying their reality.

E. W. Sinnott, an eminent American biologist, recently expressed the quandary very aptly. In his delightful little book, *The Biology of the Spirit*, he said:

> Psychology is bound to feel somewhat embarrassed over this dilemma between science and common sense. It cannot discount the importance of man's conviction that he eagerly seeks the ends for which he longs, and mechanistic psychology must either interpret these feelings as illusions with no real validity,

or else, by granting him freedom to pursue his ends, it must abandon the concept of determinism and predictability in nature. Here is the ancient dilemma between fate and freedom that has troubled philosophers and common men from ancient times to our own day. To choose between its horns seems to require the violation of one or the other of our deep convictions. Whatever our belief may be as to the ultimate nature of the universe and our relation to it, these curious qualities of man, these goals and dreams and aspirations, are worthy of much further exploration. We should not be tempted to neglect them because they do not fit precisely into present scientific ideology. These things exist. They are involved in everything we do, and it cannot be denied that they are the most distinctive elements in the character of everyone.*

A rather popular twentieth-century philosophy has been that there is no such thing as purpose in the universe. The universe is thought to be but a giant machine, arising by chance and grinding senselessly along, without meaning or purpose. This philosophy is a philosophy of despair: 'Man is but an accidental bit of cosmic dust, but we are all in it together. All that we can do is to carry on bravely, and act as though it really mattered. Man must be his own hope and future.' Supposedly based on scientific knowledge, it is called a 'scientific philosophy'. Unimaginative and superficial, it is a perversion of much human knowledge, and it is in no sense scientific. To deny that life has purpose, to deny that purpose may be a universal reality, implies that we have the means for measuring purpose and that it has been found wanting. The methods and assumptions of science are not adequate for objective study of such things as purpose and freedom. Scientific concepts cannot, therefore, include considerations of pur-

* From *The Biology of the Spirit* by E. W. Sinnott. Reprinted by permission of Victor Gollancz Ltd.

pose. Science is, after all, only one facet of human knowledge. And it is virtually impossible to live and to think as though that one facet were the entirety of human experience and understanding. To deny purpose because it cannot be found in the theories of science, is very much like denying the existence of music because you cannot play 'The Star-Spangled Banner' on a calculating machine.

11

SCIENCE AND SPIRIT

'Science without religion is lame. Religion without science is blind.' *Albert Einstein**

THERE is a large element of faith in science. Max Planck, an eminent German physicist of the early twentieth century, said that over the gates of the temple of science are inscribed the words 'Ye must have faith'. Ordinarily, faith is thought of as being part of religion, not science. Actually, in science we must accept a number of ideas on simple faith. They are ideas which we cannot test, can in no way prove, but must hold to be true. Science is a body of knowledge which has been built up on the foundation of faith that a small number of properties of the world can be taken as being obviously true. These basic assumptions, which we explored in earlier chapters, include a belief that the universe is an orderly place, that events are predictable if their underlying causes are understood. Phenomena observed under experiment are related to natural occurrences, and what is true here will be true everywhere. By faith, the scientist believes that the universe operates by one set of rules, by one all-embracing plan. By faith, it is assumed that what we can see, touch, and measure is real, and that through systematic study of these real things and measurable happenings, we can arrive at an understanding of our world.

Such assumptions – orderly cause and effect, unity,

* From *Out of My Later Years* by Albert Einstein, Constable, 1950.

understandability, and simplicity – are the articles of faith in science. They seem simple and easy to believe, and with them as a basis, science is a successful and highly exciting adventure. During the course of our brief exploration of the structure of science, we have seen something of the power of these assumptions, and how they have been used to build knowledge and to improve man's exploitation of the earth. But we have also seen something of their limitations, how each leads to a boundary, beyond which the assumptions and methods of science will not allow us to pass. A number of aspects of human inquiry and concern can be fitted into the framework of science only by serious distortion. Such limits do not destroy the scientist's faith in science; they simply define his legitimate field of inquiry.

'Faith means the assurance of what we hope for; it is our convictions about things we cannot see.' This definition of faith does not come from a treatise on the philosophy of science. It comes from the New Testament – Hebrews 11:1. It is just as applicable to scientific faith as it is to religious faith. The real differences between the faiths of science and religion concern the nature of the assertions held as being true.

The growth and flowering of a science can occur only under conditions of intellectual freedom. Their development within a civilization is dependent upon ideological permission for unhampered and unbiased inquiry. Such freedom does not come from just the economic and political structure of the society. It comes from deeper within the being of a people, from their *mores* and taboos, and from their religious convictions. The intellectual freedom so vital to science arises, or it fails to arise, from what is believed to be the meaning and purpose of man. From the ideas that are held concerning the destiny of man, his

position in the universal scheme, some degree of freedom for inquiry is derived.

Science in the modern sense took form and began its meteoric rise from within the Christian world. The Christian religion holds the belief that each person is a free agent who can, through faith, move any mountains standing in the way of his pursuit of understanding. The biblical account of creation clearly states that man is free to do what he will with his world: 'And God blessed them, and God said to them, "Be fruitful and multiply, and fill the earth and subdue it; and have dominion over the fish of the sea and over the birds of the air and over every living thing that moves upon the earth."' – Genesis 1:28. Much of Christian teaching is of the freedom and power of the human spirit. It is a liberating concept that asserts that truth will set man free, and that this freedom is reached, ultimately, by choice and faith. There is no question that must not be asked, no boundary that may not be crossed. 'Ask, and it will be given you; seek, and you will find; knock, and it will be opened to you.' – Matthew 7:7. The freedom is granted, and the way is clear for adventure in exploration of the physical world and adventure in thought and understanding. Only under such freedom could science emerge and thrive.

The early scientists had much to learn about objective thinking and controlled experimentation, for the methods of science were slow in becoming clearly defined. But they set forth with faith, confident that their inquiries into nature could not possibly yield knowledge that would be contrary to their firmly held religious beliefs. The belief that nature is unified, that the universe operates by one set of rules, is a logical assumption under the religious knowledge that there is but one universal God. It could not be assumed if it were thought that many gods might

exist. The scientific assumption that things do not happen without cause is a natural outgrowth of the religious conviction that the world has purpose and plan. The assumption that the universe is not so mysterious that it cannot be understood through patient and persistent study is a result of the belief that man was created as a participant in the universal plan. This assumption is also strengthened by the promise 'Ask, and it will be given you'. Some of the roots of science may be traced deep into human history. But science as we know it acquired its freedom, shape, and impetus from the religion of the Western world.

To be sure, a Copernicus was thought dangerously mad when he said that the earth moves around the sun, and an Inquisition forced Galileo to recant his teachings. These early growing pains came from beliefs superimposed on basic Christian beliefs, not from the religion itself. Fortunately, both the religion and the science survived and transcended the blindness of the Middle Ages. Twentieth-century science might be thought to be independent of religious and ideological limitations. Science and scientific technology now play a role of such magnitude that they should no longer be dependent on intellectual freedom granted by religion and moral tradition. It is probably true that science is now less dependent on such ideological freedom than it was in its earlier years. It is certainly not free from such influence, however. One example is the fact that in certain areas of the United States and in Spain, it is illegal to teach the principle of biological evolution. Another is the fugitive status of modern (Mendelian) genetics in Russia.

The Communist Manifesto asserts that law, morality, and religion are nothing more than 'bourgeois prejudices'. Religion is considered to be mere myth, and has been largely suppressed in Russia and other Communist coun-

tries. Individual allegiance to the 'party line' is demanded, and Communist ideology is made to replace religious doctrine. The official Communist attitude toward Mendelian genetics is that it is an idealistic product of capitalism, and that there is really no such thing as a gene. Russian children are taught that the Communist Revolution improved the Russian people, and that they have inherited the better characteristics acquired by their parents. Because of the 'improved' environment offered by Communism, each generation of Russians will be of finer stock and increasingly superior to the people of capitalist countries. For a number of years, many biologists disagreeing with this doctrine were deposed or 'liquidated'. Under such ideological restraint, unbiased research in genetics is not possible. As a result, Soviet genetics has made little progress during the last two decades. Intellectual freedom is still necessary for scientific growth, even in this scientific age.

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Although science acquired its basic, unproved assumptions from some aspects of religious belief, there is little else shared by the two bodies of knowledge. An understanding of science does not lead to an appreciation or belief in the area of religion. And conversely, sagacity in religious concepts in no way improves one's grasp of scientific matters. Science and religion are distinct and separate bodies of knowledge. They both begin with faith – simple acceptance of basic ideas. Each represents a determined and intelligent effort to achieve a universal view and a reasonable interpretation of experience. Their paths separate, however, when it comes to the methods employed in the pursuit of knowledge, and also in regard to the type of understanding sought.

The scientist deals with the observable and measurable, and this leads him to an external impersonal world and, presumably, to objective knowledge. He builds a rational physical universe, and from the technological fruit it has borne, he knows that his knowledge has meaning. The tools of measurement and objectivity are useless to the student of religion, however. The theologian deals with the intangible dimensions of the spirit, and he seeks to build a reality of the elements of love, purpose, hope, and salvation. He builds his universe in the form of an order of reality called God, and is concerned with the relationships of the human spirit to the universal spirit. As H. R. Rasmusson, a modern theologian, has put it:

> The rationality of the universe is a theory steadily confirmed by the victories of science. The doctrine of God as love, Christ as the way of peace and power, obedience to Him as the road to experience of Him, have maintained themselves through every kind of vicissitude and possess truth for thousands of people who are every bit as hardheaded and practical and realistic as any scientist. Religion says to man about Christ: 'Make the experiment and you will have the experience.' You will know this religion by what it does in you. It is not blind faith. It is faith as adventure – daring to do the will.

There can be little doubt but that the universe described by science is quite a different place from that depicted by religion. They are separate world pictures. Neither can be derived from the other. In so far as science and religion deal with distinctly different aspects of human experience, their two universal interpretations are not mutually exclusive. That is, it is not a matter of one being necessarily 'wrong' and the other necessarily 'right'.

A question was posed in Chapter 1, a question of the relevance of science to all human knowledge. Might

science and the methods of science eventually provide the means for solving all basic human problems, including the so-called spiritual ones? The ensuing chapters were devoted to an examination of the foundations and essential structure of science. And it was found that science has some intellectual limitations. A problem can be pursued scientifically very effectively, but eventually a boundary is reached. Beyond this boundary the methods and tenets of science are no longer valid. It would seem that philosophical and religious beliefs dictate our interpretations, once we pass beyond the limits of science. The individual person, living under the strains and conflicts of a complex, swiftly moving society, has a great need for beliefs to which he can tie his life, for convictions that will give him real stability and understanding. It is, therefore, important that the degree of compatibility between religious knowledge and scientific knowledge be clarified. This is a point about which there is much confusion. Our exploration of the structure and meaning of science would be incomplete without a consideration of this important subject. In the discussion of this complex and controversial problem, I cannot pretend that I speak for all scientists, or that my interpretation is uncoloured by the philosophy to which my own experience and thinking has led me.

Science and religion sometimes appear to be in conflict. This is because of a human element; it is not easy to keep the terms and tenets of the two clearly separated. Scientific concepts must not be judged on the basis of how well they fit into religion, and religious concepts must not be judged as to their relevance to science. The result would be only a chaos which would be meagre religion and poor science. Fundamental concepts are less likely to be in disagreement than are some of the ideological trimmings that

have been added to both science and religion by implication. The religion-versus-science controversy over the scientific theory of biological evolution is an example. This argument was touched off by Darwin's theory just one hundred years ago.

The theory of evolution by natural selection says that higher animals have evolved from lower forms by a mechanism of selective survival, based on individual fitness. Many theologians were immediately opposed to the theory because it meant that man may not have been created outright and perfect in a garden one day. It seemed to cast some doubt on the dignity of MAN, and made him only man, the distant cousin of an ape. The tendency was to claim that if the theory of evolution was sound, the Holy Bible was a book of lies. As one prominent theologian of the time put it, 'If the Darwinian theory is true, Genesis is a lie, the whole framework of the book of life falls to pieces, and the revelation of God to man, as we Christians know it, is a delusion and a snare.' This was a very dangerous intolerance.

Biologists and other scientists accepted Darwin's theory on the basis of its immense scientific merit, and evidence in support of the theory came piling in from the four corners of biology. Only then did the theologians begin to realize that their dogmatic opposition might destroy the Christian church. For what would happen if the Darwinian idea proved to be right, after all? Slowly the theologians' attitude toward evolution changed to one of allowing that perhaps God had created man via an evolutionary process.

As long as a scientific theory stays within the bounds of science and deals with natural phenomena by the methods of science, the theologian must recognize its scientific merit and avoid theological pronouncements concerning

it. Religion must, certainly, allow spiritual growth, but such growth cannot occur if beliefs are bound with steel bands of dogmatic intolerance. A faith is small if it fears reality.

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It is often said that agnosticism is the proper attitude of the scientist – that the scientist does not make up his mind until all of the facts are in. This idea is utterly false. If it were true, we would still be waiting to make the first hypothesis. It seems unlikely that all of the facts will ever be in. And how would we know what to look for, what experiment to run, without some prior knowledge? Knowledge can, after all, be improved and increased only by using previous knowledge as a springboard, a point of departure. Scientific investigation begins with what has been observed; facts are marshalled, and a tentative interpretation is made. This is called a hypothesis. The hypothesis is a form of knowledge, and is held to be true, although little confidence is held in it until it can be tested. When the hypothesis is tested, it leads to more refined knowledge. The hypothesis is strengthened, weakened, or destroyed by the results of the experiment. Then a better idea is held and tested. But the best available idea, the interpretation most consistent with all of the observed facts is treated as being true. Scientific theories and laws are used deductively; that is, as the basis for prediction. And if they are to be so used, they must be accepted as being true. A good scientist does not become dogmatic, however. He does not reach the point of saying that a particular theory is absolute and no further knowledge is possible. This is not agnosticism; it is only the absence of bias.

A person – scientist or non-scientist – may become so

impressed with the magnificence of science and so imbued with the power of the scientific method, that he may attempt to make science a way of life. This tends to make a religion of science, a philosophy which has been called *scientism* or *scientific humanism*. Scientism asserts that Christianity and other formal religions have failed, and that the only true knowledge is scientific knowledge. The only pathway to understanding is through the laboratory. Any conviction not backed by verification via the scientific method is untenable. All other forms of knowledge are held to be mere by-products of the human brain, patterns of thinking and superstition, as it were. Purpose, beauty, aspiration, immortality, have no reality; they are not to be found except through wishful thinking.

It is a great and fundamental mistake to assert that any one body of knowledge constitutes the only true knowledge. To so limit the validity of human thought and experience is a narrow-minded approach to understanding. It can lead only to a cramped and desperate view. Science does not provide a philosophy, a religion, a way of life. The attitude that science is the only avenue to truth cannot be consistently maintained, for it is to try to live in a universe of measurements. It is to ascribe reality to only the measurement, while denying that that which was measured can, in any sense, be known. This sort of reasoning has led some to describe a ray of light as a ray of knowledge.

We are confident that science is a measure of what goes on in the world, but we have no reason to believe that this measurable reality is the only knowable reality. As was pointed out in the discussion of vitalism and mechanism and of the problem of purpose, science is not a 'nothing but' approach to nature. It does not show that knowledge is necessarily nothing but measurements. It does not prove

that religion is nothing but wishful thinking. Science does not lead inevitably to scientism. Scientism is a philosophical system which does lip service to science in an effort to camouflage its dogma.

If, as scientism proposes, religious knowledge should be discarded in favour of scientific interpretation, a number of serious problems arise. One of these problems has to do with ethical standards. On what basis could we build a standard of desirable human behaviour? A number of suggestions have been made. None of them is in any sense scientific, however, because science has nothing to say on the subject of ethics. Science deals with things and events as they actually occur; that is, science is concerned with 'what is', and not with 'what ought to be'. Efforts to find an ethical standard in scientific knowledge, biology in particular, have been quite unsuccessful. The difficulty is that it is necessary to decide beforehand what kind of an ethical standard is to be considered appropriate for effective human conduct. Only then can biological parallels be found. Comparing a society to a living organism, with the action of each part being directed towards the maintenance and welfare of the whole body, is an appealing biological analogy. A standard of behaviour which treats each individual as a single cell in the body of a superorganism, and demands that he act always in the interest of the social organism, would probably lead only to the blind slavery of the beehive. No room for individual freedom would be found, and the system would lead to homogeneous, standardized populations.

It has also been suggested, quite seriously, that human behaviour and the shape of human society should be determined by man's responsibility to biological evolution. This idea is based on a particular interpretation of biology, according to which only genes have any real

importance. The organism is merely a gene-carrier synthesized by the genes themselves. Evolution is the result of natural selection for more efficient gene carriers. The human race is responsible for seeing that this process is continued, so that better and higher types of human beings may be evolved. This philosophy is in no way scientific; it is not a necessary – or even very plausible – consequence of biological knowledge. Under such a plan, there would undoubtedly be considerable difficulty in deciding just what constitutes the most desirable direction for human evolution to take. It could, at best, lead only to the type of meaningless society described by Aldous Huxley in his satirical science-fiction story *Brave New World*.

In contrast to these 'scientifically based' suggestions, the code of ethics which is part of the Judaeo-Christian tradition provides opportunity for a maximum of freedom, personal responsibility, and spiritual growth. It has frequently been suggested that the Christian ethics be retained, while the rest of the religion should be discarded as myth. Clearly, this is not possible, for the ethics depend on the religion for their meaning and authority. Without the religion as the basis, the ethics would tend to shift with the expediencies of the times. There is a need for ideals in the life of an individual and in the life and growth of a society. In science, too, ideal concepts are needed as the basis of natural laws. These ideals are quite unattainable, and yet they are powerful guiding principles. They provide the standards by which scientific progress is measured.

One of these scientific ideals is called absolute zero. Absolute zero is the lowest possible temperature (459·7° F. below zero). At this fantastically low temperature, all molecular and atomic motion would cease. It is not pos-

sible to produce absolute zero in a laboratory, although it is possible to come very close to it. Even though it cannot actually occur, absolute zero is a useful and important scientific concept. Physical laws are also ideal concepts. One of Newton's laws of the physical universe says that a body in motion will continue in uniform motion in a straight line until some outside force acts upon it. This is an ideal; actually it is not possible to have a body that is not being acted upon by outside forces – gravity, for instance. As an ideal concept, however, it has long been a powerful force in science. Ideal gases, ideal sensory responses, ideal experiments, are all unattainable from a practical standpoint. Nevertheless, they form the terms of scientific theory; they set the goals toward which we strive. Because our science is not perfect, and because we cannot work in isolation from the universe, these ideals cannot be fully realized. No scientist would suggest, however, that we abandon them. Without such guiding ideals, science would become haphazard and progress would shortly cease.

In the realm of spiritual growth and awareness, religion provides a guiding universal ideal. Because humans are not perfect beings, these ideals are essentially unattainable. Christianity teaches that only a perfect person, Christ, could live a perfect life, but as long as this ideal is held before us and our lives are directed toward it in faith and sincerity, the ideal can be approached. To many people, this is sheer myth and mysticism. In this world of practicalities – satellites and wars and depressions – there seems little room or reason for such ideals. They may be quite willing to accept on faith the idea of scientific ideals which cannot be realized, and yet unwilling to subscribe to comparable spiritual ideals. To discard the spiritual ideal, but retain the ethics which arise from it, seems no

more practical than to discard idealized scientific laws but retain the knowledge which is consequent from them.

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Over half a century ago, Edwin A. Abbott, an English minister, published a fantasy entitled *Flatland.* It was based on an intriguing idea: Flatland was a two-dimensional world and was inhabited by two-dimensional people, Flatlanders. The world of our common experience is three-dimensional; things have length, breadth, and depth. In Flatland, however, there was no depth. People and objects had length and width only. Their world was simply a surface, like a sheet of paper, and the Flatlanders were figures, such as triangles and circles, drawn on the surface. Flatlanders had no idea whatsoever of a third dimension, no inkling of up and down. Their movements, their experiences, and their thoughts were limited to the two dimensions of their peculiar existence. They encountered problems which their two-dimensional scientists could not solve. The origin of light was such a problem. They found light in their world, but they could not tell where it originated, since they had no conception of space in more than two dimensions.

One of the Flatlanders, the hero of the fantasy, experienced a visitation or revelation, in which he was granted knowledge of three dimensions. In his vision, he was transported into a world of three dimensions. To him, this was a most glorious and transcendental experience, and he determined to tell his fellow Flatlanders of it. The Gospel of Three Dimensions was to be a gospel of a new world, a different world, more glorious and meaningful than Flatland. This new world was their Flatland plus a dimension outside of their experience, knowable to them

only by revelation. So inspired, the little Flatlander set out to evangelize all of Flatland. But in order to explain the third dimension to others, he had to use their language and to express himself in their concepts and within their world of experience. This he found he could not do. He could not make himself understood; his inspiration was not intelligible to Flatland logic. Eventually he was put into an asylum for the incurably insane. Even there, he continued to write and dream of the world of the New Dimension. But as time went on, he had difficulty in separating his own mind from Flatland practicality, and he encountered more and more difficulty in keeping the memory of his revelation sharp and clear.

Such is the essence of Abbott's fantasy of Flatland. The moral is, of course, that there may be aspects of reality that can be known only imperfectly, and that cannot be made intelligible by our language and logic alone. The deepest insights and highest visions in the arts, religion, and science undoubtedly suffer from the means of their communication. By virtue of mathematical symbolism, scientific interpretations are more easily communicated than are those of the other intellectual interests. To deny the validity of intuitive knowledge, to deny that religious thought and experience have any real meaning, on the basis that they cannot be tested, measured, and expressed in scientific terms, is to be but a Flatlander. Abbott's story is sometimes hailed as a prophecy of some aspects of Einstein's relativity theory. This is giving him more credit than is probably his due, but illustrates the point that what may seem only unbridled fancy today may be accepted scientific theory tomorrow, depending on how the idea is symbolized and communicated.

*

Schemes and dreams have borne rich fruit in scientific progress, whenever material techniques have been developed by which they may be tested, refined, enlarged, and handed down to subsequent generations. The human mind also makes excursions into areas and produces thoughts and conclusions which cannot be tested at that same material plane. This limitation makes them harder to refine and enlarge and pass on, but it does not make them necessarily mere fantasy.

Many leading scientists down through the years from Galileo to Einstein have been deeply religious. They have been intrigued by the essential mystery of life and material existence, and have recognized that spiritual as well as scientific understanding is needed. Sir Isaac Newton said that in the beginning God created matter in the form of hard, glassy, indivisible particles. Albert Einstein helped to destroy Newton's marble-like particles, but not Newton's God. Einstein could not accept the idea that chance rules supreme in the universe. He spent many of his later years trying to disprove the uncertainty principle. As he once put it, 'I cannot believe that God plays dice with the universe.' Other scientists, more willing to accept concepts of probability, have found it necessary to assume the existence of an anti-chance, or anti-probability, as an organizing force, in order to make sense of natural phenomena. It is but a short step from the idea of anti-chance to the idea of God.

Two biologists might examine a living cell under a microscope. One will see there the handiwork of God; the other will see *only* what evolution has chanced to produce. And yet both will agree on the cell's biological history, its composition, its structure, and its function. One physicist will find God in the exquisitely organized and exact laws of the physical universe. Another physicist

will not be able to see anything beyond the laws themselves. The religious views of a scientist do not come from his science; they come from his entire philosophy, his whole view of the world. But scientists are not unique in this matter; the same disparity of thinking is to be found among people from all walks of life.

In the modern world, science serves two important functions. One is to provide the basis for a scientific technology. It is in this way that science has the greatest influence on our daily living. Through technology, we advance the structure of civilization and gain increasing domination over the earth and (within a few years) adjoining portions of the universe. The other purpose served by science is one of understanding. Through science, we discover how phenomena occur and, to a limited extent, why they happen the way they do. Vital processes are studied and analysed, that we may know more of how organisms function, and how they have come to be what they are. Through science, we seek to know what a man is – how his body works and why he thinks and dreams. As we search to know ourselves and the workings of our minds, we expect to find solutions to problems of confusion and discontent. Science is a way to understanding, but in some ways it is a narrow path that does not touch on all the questions posed by the facts of human life. Science does not provide a way of life; it does not create a moral order. It is quite obvious that not all meaningful human knowledge can be reduced to scientific terms. Interpretations of ultimate meaning and value in human terms will, in the final analysis, be made more on the basis of spiritual awareness than on scientific acuity.

The problem of nations living in peace on this crowded and explosive planet is not a scientific problem. Nor will

it be solved through the use of scientific technology in the art of hot and cold warfare. If the problem can be solved, it will be through a meeting of minds, through free communication in all areas of human endeavour, including science, religion, art, and technology. It must come through the realization of the brotherhood of man, and of the fact that human life has meaning and purpose beyond the immediate propositions of day-to-day living. We must grow in spirit as well as in science. Certainly, our science will have an ever larger place in the future of our civilization. But if religion is not also there as a guiding force in shaping the lives of individuals and the policies of nations, civilization may end as radioactive rubble. Both science and religion, both ways of making world and life coherent, have vital roles to play in the future of human affairs.

POSTSCRIPT

ALTHOUGH the end of the book has been reached, its subject has not been exhausted. Indeed, a mere beginning has been made. This book has been successful only if it has aroused the reader's interest in finding out more about science – how it works and what it means. In this writing, I have attempted to provide a background of information and a frame of mind which will aid in understanding more detailed discussions of the subject. The books listed below are recommended for further reading. They are but a few of the many that are available and worthy of recommendation.

GARDNER, MARTIN, *Fads and Fallacies in the Name of Science*, Dover Publications, New York, 1957.

This is a readable and penetrating analysis of pseudo-science and the personalities of the originators of fads and fallacies. The subject matter ranges from dowsing to sex theories. It is a highly entertaining and somewhat disturbing book.

NEWMAN, JAMES R., *What is Science?* Simon & Schuster, New York, 1955.

This is a compilation of essays on various aspects of science and philosophy. The editor has brought together some of the thoughts of men who have been outstanding in their scientific fields. It is not always easy reading, but it offers the reader a good cross-section of modern science.

NOÜY, PIERRE LECOMTE DU, *Human Destiny*, Longmans, Green, London, 1947.

The author is a biophysicist who, in this volume, explores the relationships between scientific and spiritual concepts. Em-

phasis is put on evolution, past and future, as a purposeful, creative process.

OPPENHEIMER, J. ROBERT, *Science and the Common Understanding*, Simon & Schuster, New York, 1954.
A brilliant physicist explains the principal concepts of atomic physics. This small, beautifully written book traces modern developments with both authority and clarity.

SINNOTT, EDMUND W., *The Biology of the Spirit*, Victor Gollancz, London, 1956.
A biologist's outcry against rigid mechanistic biology, this is a readable and thoughtful book. The author develops a philosophical interpretation of growth, orientation, and behaviour.

SULLIVAN, J. W. N., *The Limitations of Science*, Chatto & Windus, London, 1933.
This book explains modern scientific concepts and their limitations. Emphasis is on the physical sciences. Although parts of it are out of date, and some sections are difficult reading, the book is still well worth reading.

WHITEHEAD, ALFRED NORTH, *Science and the Modern World*, Cambridge University Press, London, 1925; and Penguin Books, Harmondsworth, 1938.
Written by one of the greatest intellects of the twentieth century, this is a classic in the field of the philosophy of science. Much of it is very difficult reading, and must be re-read to be appreciated.

No one works or thinks in isolation, alone in the world. The published thoughts and efforts of many writers have contributed to the contents of this book. To them I am deeply indebted, even though brevity and simplicity have prevented proper acknowledgement of their specific thoughts. More immediate and tangible is my indebtedness to those who contri-

buted to this writing through their suggestions, criticisms, and encouragement. In addition to my wife, Isabel, whose aid has been invaluable, I owe much to Wallace Wickoff, Karl F. Schmidt, Richard K. Winslow, Professor James F. Crow, and the Rev. Charles S. Anderson.

INDEX

MASS, LENGTH AND TIME

NORMAN FEATHER

A532

Measurements of mass, length, and time are the fundamental measurements in physics. Professor Feather traces the history of the emergence of these concepts, with their associated systems of measurement, from the earliest times. On this basis the whole subject of the mechanical properties of matter in bulk is developed. A unique feature of the book is its complete exclusion of the calculus, in any formal context. The author's express intention is to provide an understanding of principles and he devotes chapters to different kinds of motion, to force, mass, and inertia, to gravitation, energy of various sorts, elasticity, and surface tension. His biographical notes on the physicists he mentions add direct human interest to this explanation of 'what Physics is all about'. For essentially this book offers a friendly introduction to the science of Physics.

'What the author has in view ... has been done admirably, in a way that will stimulate the general interest and broaden the mind of the youthful reader' – Professor Andrade in the *New Scientist*

published by Penguin Books

The Simplicity of Science

Disraeli used to speak of 'the two nations'. Sir Charles Snow and others warn us today against the dangers of 'the two cultures'.

We know the humanist, with his traditional culture of literature, languages, history, and the arts. But how well do we know the scientist, whose influence, in the last twenty years, seems to have rocketed up from a vertical take-off? How does his mind work? What are his fundamental assumptions? By what processes does he arrive at his conclusions? What values are there in his world? And are these enough?

In this unusual book Dr Beck, an American zoologist, has clearly set out the basic concepts of science in terms we can all understand. He explains the logical progress of hypothesis, experiment, observation, theory, and other stages along the path towards the discovery of the nature of things. He presents science, with its tightly-linked chain of reasoning, as a vital tradition of human thought. Above all, he engages our sympathy.

Such books as this powerfully help to narrow the gap between scientist and non-scientist.